DEPARTMENT OF THE INTERIOR
JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

BULLETIN 704

GEOLOGY OF THE IGNEOUS ROCKS OF ESSEX COUNTY, MASSACHUSETTS

BY

CHARLES H. CLAPP

WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

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GEOLOGY OF THE IGNEOUS ROCKS OF ESSEX COUNTY, MASSACHUSETTS.

By Charles H. Clapp.

INTRODUCTION.

LOCATION AND GEOLOGIC INTEREST OF THE AREA.

Essex County is the northeasternmost county in Massachusetts and has an area of about 525 square miles. (See Pl. I, in pocket.) The special area (see Pl. II, in pocket) whose geology is more particularly discussed in this bulletin lies almost wholly in southern Essex County, comprising the southern part of the Lawrence, the northern part of the Boston Bay, the southeast corner of the Salem, and the northeast corner of the Boston quadrangles. It includes about 196 square miles.

Geologically the area is well known, chiefly because of its alkaline igneous rocks, among which are the types essexite and bostonite. Besides presenting local problems the area illustrates certain general features of the geology of igneous rocks, the more important of which are:

1. The sequence of the volcanic, batholithic, and dike phases of an igneous cycle.
2. The differentiation of two contrasted groups of rocks, the subalkaline, or calci-alkalic, and the alkaline.
3. The origin of shatter breccias along molar contacts of batholiths and the slope of molar contacts.
4. The contact assimilation of country rock by invading igneous magmas, forming hybrid rocks.
5. The formation of diabase dikes contemporaneously with irruptions of alkaline granitic rocks.

OBJECT OF THE REPORT.

This report embodies the results of several years of interrupted work in the county. Its object is:

1. To publish the writer's conclusions concerning the general relations of the igneous rocks of Essex County in order to make future more detailed work easier and of greater value.
2. To make known the large amount of scattered and unpublished work by the members of the geologic staffs and by students of the Massachusetts Institute of Technology and Harvard University.

3. To throw light on some of the broader principles of the geology of igneous rocks, notably the formation of hybrid rocks by contact brecciation and assimilation and by impregnation of invaded rocks, and the differentiation of subalkaline magmas.

PREVIOUS WORK.

The first valuable geologic work in Essex County was begun by Edward Hitchcock during the first geological survey of Massachusetts, the final report of which was published in 1841. During the next 40 years a large amount of work was done by local geologists, some of them renowned (Agassiz, Hunt, and Hyatt). In 1880 Crosby [1] published a thesis on the geology of eastern Massachusetts, in which he included some results that he had published as early as 1876. His work called forth a great deal of discussion, in which M. E. Wadsworth [2] took the opposing side in favor of the volcanic origin of the so-called petrosilex. Wadsworth [3] published also several valuable papers on the petrography of the igneous rocks of the region. J. P. Cooke [4] and others published descriptions of many of the rare minerals occurring in the granite (Quincy granite) and pegmatite at Cape Ann. About the same date several papers by local geologists were published, a full bibliography of which is given by Sears.[5] In 1889 Shaler [6] published a paper on the geology of Cape Ann, which, however, dealt chiefly with glacial geology.

J. H. Sears, late curator of geology, mineralogy, and botany of the Peabody Institute, Salem, spent a long time in studying and mapping the geology of Essex County. He published several papers[7] during the progress of his work and later summed up his results in a memoir of over 400 pages,[8] which served to bring to the attention of petrologists many of the interesting igneous rocks of Essex County, notably essexite, which he first described and named in 1891. Unfortunately his field work is unreliable.

In 1898 and 1899 H. S. Washington[9] published detailed petrographic descriptions of most of the rock types of Essex County and gave analyses of the more important ones. His work has added much to the knowledge of the rocks and is of the greatest help to the

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1 Crosby, W. O., Contributions to the geology of eastern Massachusetts: Boston Soc. Nat. Hist. Occasional Papers, No. 3, 1880.

2 Wadsworth, M. E., Boston Soc. Nat. Hist. Proc., vol. 21, pp. 292–293, 1883; vol. 22, pp. 130–133, 1884.

3 Idem, vol. 19, pp. 217–237, 309–316; 1878; Geol. Mag., 3d decade, vol. 2, pp. 207–210, 1885.

4 Cooke, J. P., Am. Jour. Sci., 2d ser., vol. 42, p. 73, 1866; vol. 43, pp. 217–230, 1867.

5 Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., pp. 406–411, Salem, Mass., Essex Inst., 1905.

6 Shaler, N. S., Geology of Cape Ann, Mass.: U. S. Geol. Survey Ninth Ann. Rept., pp. 529–611, 1889.

7 Essex Inst. Bull. 22, pp. 31–48, 1890; Bull. 23, pp. 145–155, 1891; Bull. 25, pp. 111–125, 1893; Bull. 27, pp. 109–112, 1895.

8 Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., 418 pp., Salem, Mass., Essex Inst., 1905.

9 The petrographical province of Essex County, Mass.: Jour. Geology, vol. 6, pp. 787–808, 1898; vol. 7, pp. 53–64, 105–121, 284–294, 463–482, 1899.

geologists working in Essex County. H. Rosenbusch[1] and Fred E. Wright[2] also have described several rock types collected from Essex County by Sears. More recently Dale[3] has described the granite of the Cape Ann district chiefly as building stone.

FIELD WORK.

The writer began work in Essex County in 1905 as an undergraduate student in the Massachusetts Institute of Technology, working with Mr. W. G. Ball in the neighborhood of Newburyport. He did little work in 1906, but in the fall of 1907 he began detailed investigations in the southern part of Essex County (the area shown in Pl. II, in pocket) and the adjacent portions of Suffolk and Middlesex counties and continued them through the spring and fall of 1908 and 1909. In the spring of 1910 he made a general reconnaissance of the whole of Essex County in order to connect the different areas to which he had given more detailed study.

In the field work the writer has had access to the original notes or has had oversight of the work of several students of the Massachusetts Institute of Technology. Those who have done special work are W. L. Spaulding and E. Burton, 1905; J. G. Barry, 1907; W. Hastings, 1907; K. G. Chipman and J. W. Maxwell, 1908; J. S. Pearce and B. A. Robinson, 1909; J. D. MacKenzie, 1911; and A. C. Metz, 1911. The notes and specimens of S. J. Schofield and N. L. Bowen, graduate students from 1908 to 1912, have been available also, as well as those of Prof. C. H. Warren. The compiled results of the field work of the class of 1902 of Harvard University have been examined, and also the notes and specimens of F. W. Lovejoy, 1901; J. W. Eggleston, 1906; and E. J. Saunders, 1906, all Harvard University students. A. C. Lane's unpublished doctor's thesis on the geology of Nahant has also been used.

ACKNOWLEDGMENTS.

The writer is indebted to all the members of the geologic department of the Massachusetts Institute of Technology, in particular to Profs. Warren and Daly, for their oversight of the field and laboratory work, and to Prof. Crosby, under whose direction the writer began field work in Essex County in 1905. He is also indebted to Messrs. M. F. Connor and S. J. Schofield for chemical analyses.

GENERAL SUMMARY AND CONCLUSIONS REGARDING THE IGNEOUS ROCKS.

The igneous rocks of Essex County have been separated into the two great groups recognized by most petrologists, the alkaline and

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[1] Min. pet. Mitt., vol. 9, p. 447, 1890.

[2] Idem, vol. 19, p. 318, 1900.

[3] Dale, T. N., The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: U. S. Geol. Survey Bull. 354, pp. 121-140, 1908.

the subalkaline. The rocks of these two groups were irrupted at different times that were separated by a long period of erosion. The older group, the subalkaline, consists of granites, granodiorites, quartz diorites, gabbro-diorites, and gabbros. All these rocks have been greatly metamorphosed by dynamic and contact metamorphism and have been subjected to long secular weathering. The rocks of the younger group, the alkaline, which are intrusive into those of the older group, consist chiefly of alkaline granites and alkaline and nephelite syenites with some diorite, diabase, and gabbro. They are relatively unaltered and unmetamorphosed rocks and therefore present a great contrast structurally as well as mineralogically and chemically to the rocks of the subalkaline group.

The subalkaline batholith was intruded in post-Ordovician (Devonian?) time into a series of closely folded metamorphic sediments and volcanic rocks of Cambrian and Algonkian (?) age. The roof of the batholith was removed by erosion during the cycle initiated by the deformation of the Cambrian and Algonkian (?) strata and the upper part of the batholith was exposed. The upper part of the batholith is the most felsic, for the old erosion surface, still preserved by an unconformable covering of volcanic rocks, is everywhere of granodiorite (Dedham granodiorite), which passes downward through quartz diorite (Newburyport quartz diorite) into gabbro-diorite (Salem gabbro-diorite), the staple rock of the batholith. This arrangement of the three subalkaline types accords with their respective densities, the uppermost, the Dedham granodiorite, being the lightest. It is doubtless the result of magmatic differentiation, which proceeded under gravitative control. The parent magma was doubtless basaltic and its differentiation is believed to have occurred in place through fractional crystallization. The first silicate mineral to form, olivine, has either been redissolved or has sunk to a lower zone in the batholith than has yet been exposed. The residual magma crystallized largely as the olivine-free Salem gabbro-diorite, but the last portion of the magma to crystallize collected near the top of the magma chamber and solidified as the Dedham granodiorite.

The erosion of the subalkaline batholith was followed by the irruption of the alkaline rocks, which took place in the normal order of irruption of the various phases of activity in an igneous cycle—that is, volcanic, batholithic, and dike or injected phase. The alkaline volcanics were accumulated upon the eroded, granodiorite surface of the subalkaline batholith. The alkaline volcanic series (Lynn volcanics) is characterized at its base by a coarse agglomerate, but the larger part of it consists of tuffs and flows, chiefly quartz keratophyres, some of which were glassy but are now devitrified. The irruptions of the volcanics were doubtless largely of the central type, the sites of former volcanoes being represented by rounded areas of very coarse and heterogeneous agglomerate.

The Lynn volcanics, with the sedimentary rocks of the Merrimack Valley, which were also deposited on the eroded surface of the subalkaline batholith, were folded, probably in middle Carboniferous time. Concomitant with this deformation the alkaline batholiths were irrupted. Their staple rock is granite, which is of two types—the hornblende-microperthite granite of Peabody and Cape Ann (Quincy granite) and the muscovite-biotite granite of Andover (Andover granite). The granite batholiths of Peabody and Cape Ann are characterized by a large number of rock types at their outer zones. These types are largely alkaline granites and alkaline and nephelite syenites, which are very closely related in mineral and chemical composition to the normal granite and are almost certainly marginal differentiates of the original alkaline magma. The granite batholith of Andover is more uniform in character but has many felsic facies, such as muscovite granites, alaskites, and pegmatites. Although apparently younger than the Peabody and Cape Ann batholiths, it is gneissic, but the gneissic structure is apparently primary, having been largely produced by deformation during the intrusion of the batholith.

The irruption of the Cape Ann and Peabody batholiths was accompanied by the intrusion of many dikes of varied types, which range from felsic quartz porphyries to camptonites and diabases and yet are all virtually transitional. Most of them are confined to the contact zones of the batholiths, and although they cut the normal granite and alkaline syenite they are cut by apophysal phases of the granite and syenite. Their close relation to the batholithic rocks is shown also by their mineralogic and chemical similarity and they are doubtless largely marginal differentiates of the alkaline batholiths and are, therefore, diaschistic dikes, the felsic and mafic dikes being complementary. However, some of the dike rocks may be the result of contact assimilation or hybridism.

The granite of Peabody and Cape Ann was intruded into the crystallized subalkaline batholith, largely into the lowest or gabbro-diorite zone. The present contact between the gabbro-diorite and the alkaline granites is marked by extensive contact shatter breccias. The nature and extent of the breccias strongly suggest that they were formed by differential expansion of the gabbro-diorite, caused by rapid heating near the intruding alkaline magma.

At the contact a great amount of both exomorphic and endomorphic metamorphism has taken place. The gabbro-diorite has been recrystallized and infiltrated with material from the alkaline magma. In the contact shatter breccias the xenoliths of gabbro-diorite not only have recrystallized but contain new minerals, the materials of

which must have been derived by infiltration. On the other hand, the recrystallization of material derived from the xenoliths has enriched the irruptive magma in mafic minerals at the contacts, thus forming hybrid rocks.

The hybridism is the result of the action of the magma on relatively cold rocks and "accidental" xenoliths and is very extensive. Some of the hybrid rocks resemble some normal differentiates; and the essexite of Salem Neck is apparently a hybrid between subalkaline gabbro or olivine diabase and nephelite syenite.

The irruption of the dike rocks related to the alkaline batholiths was followed by the injection of large dikes of brown-weathering diabase, which are correlated with the Triassic diabase dikes that cut the strata of the Newark group. The injection of these dikes closed the igneous geologic history of Essex County.

The igneous geologic history is summarized and the relative ages of the numerous rock types are shown in the following table, the rocks being given in the order of their eruption, from oldest to youngest, according to the views of the author:

A. Subalkaline group (Algonkian? to Devonian?).
  1. Metavolcanics, chiefly andesites and basalts involved with Cambrian and Algonkian (?) sediments, doubtfully included in the subalkaline group.
  2. Batholith of post-Ordovician (Devonian?) age.
    a. Salem gabbro-diorite with olivine-bearing gabbro facies.
    b. Newburyport quartz diorite.
    c. Dedham granodiorite with calci-alkaline granite facies. These three types are transitional, no type cutting any other, although inclusions of its calci-alkaline facies occur in the Dedham granodiorite.
  3. Batholith cut by
    a. Granodiorite aplite.
    b. Diabase dikes.

B. Alkaline group (Silurian? to late Carboniferous or post-Carboniferous).
  1. Gabbro and diabase porphyries at Nahant (Silurian or Devonian). Position in table and correlation doubtful.
  2. Lynn volcanics (Devonian? and Carboniferous). Quartz keratophyres, trachytes, dacites, and andesites, with dikes of similar rocks and one bostonite dike.
  3. Batholiths of Carboniferous age.
    a. Beverly syenite.
      Pulaskites and umptekites, forming peripheral masses and later apophyses.
      Apophyses and dikes of pulaskite aplites and pegmatites and hedrumitic pulaskites.
    b. Quartz syenite (nordmarkite) and nephelite syenite.
    c. Quincy granite.
      Normal.
      Peripheral phases of porphyritic granite, "fine-grained" granite, and Squam granite (intrusive into Quincy granite). Apophysal phases of aplite, microcline granite, aplite, and pegmatite.

B. Alkaline group—Continued.

4. Dikes related to Quincy granite and to Beverly syenite. They cut the main batholiths but with the exception of the youngest diabases are cut by aplites, pegmatites, and "fine-grained" apophysal phases.
   - *a.* Olivine diabase porphyries.
   - *b.* Camptonites, vogesites, kersantites, minettes, amphibole fourchite, sölvsbergites, tinguaites, and some diabases with tabular feldspar phenocrysts.
   - *c.* Diabases with tabular feldspar phenocrysts.
   - *d.* Quartz porphyries and paisanites.
   - *e.* Diabase porphyries.
5. Gabbro associated with Dracut diorite (late Carboniferous or post-Carboniferous age, according to Emerson).
6. Batholith of late Carboniferous or post-Carboniferous age.
   - Andover granite.
     - Normal.
     - Muscovite granite facies.
     - Aplites and pegmatites.

C. Diabase dikes of Newark group (Triassic).

REGIONAL GEOLOGY.

Essex County belongs to the northeastern part of the Appalachian geologic province, which includes the larger part of New England, eastern Quebec, and maritime Canada. It differs from the central Appalachian province in its great complexity. The rocks are chiefly of Paleozoic age, although some are pre-Cambrian. The Paleozoic formations are divided into three large groups, the older metamorphic rocks, of Cambrian and Ordovician age, which include slates, quartzites, marbles, and schists, with basic effusive volcanics; the Silurian, Devonian, and early Carboniferous formations, which include some highly metamorphic rocks and acidic volcanics; and the relatively unmetamorphosed but folded sedimentary rocks of Pennsylvanian and possibly Permian age. The New England province is characterized also by large granitic batholiths which have been intruded into the folded Paleozoic rocks, usually along the anticlines, so that the batholiths have an elongate outline which conforms with the general northeast-southwest Appalachian trend.

The first great orogenic movement, the Taconic revolution, took place at the close of the Ordovician period. The whole province was involved, and the Cambrian and Ordovician formations were bent into closed folds with steep dips. It is also probable that the folding was quickly followed, as it almost certainly was in eastern Massachusetts, by granitic intrusion, through which the Cambrian and Ordovician rocks were metamorphosed.

Unconformably upon these metamorphic pre-Silurian rocks, the Silurian, Devonian, and early Carboniferous sediments, largely of fine-grained argillaceous and calcareous material, were laid down. In Nova Scotia, Maine, the St. Lawrence basin, and probably in eastern

Massachusetts contemporaneous volcanism took place, and volcanic flows and breccias were intercalated with the sedimentary rocks.

In middle Carboniferous time another period of folding took place. Locally the involved formations were intensely folded, even converted into schists, as in eastern Massachusetts and Nova Scotia, but in Maine and the St. Lawrence Valley they were not greatly disturbed. In Maine there appears to have been a period of folding and granitic intrusion in early Devonian or late Silurian time.[1] The folding of the Silurian and Devonian and early Carboniferous sediments was accompanied by granitic intrusions on a very large scale. During this time the batholiths of alkaline hornblende and biotite granites were irrupted, with their satellitic syenitic bodies, which compose the Novanglian petrographic province of Pirsson and Washington.[2]

The irruption of the granitic rocks was followed by a period of erosion, after which, in Nova Scotia, Pennsylvanian and probable Permian sediments were laid down unconformably upon the granitic rocks. The same sequence probably also occurred in eastern Massachusetts, for it is probable that sediments of the Boston Basin, which are tentatively regarded as of Permian age, lie unconformably upon some of the alkaline granites. Loughlin[3] has shown that in the southern part of Rhode Island alkaline biotite granite is intrusive into sediments which have been correlated with known Pennsylvanian sediments of the Narragansett Basin, but there is a strong possibility that an unconformity, not yet recognized, exists in the Narragansett Basin.

Unconformably upon the Paleozoic rocks in Nova Scotia and in the Connecticut Valley lie the sandstones of the Newark group of Triassic age. Interbedded with and injected into the Newark strata are thick diabase flows and sheets. Dikes of similar diabases cut the late Carboniferous sediments in other parts of New England and have been very generally correlated with the diabase dikes which cut the Newark strata.

GEOLOGY OF ESSEX COUNTY.

METAMORPHIC AND SEDIMENTARY ROCKS.

The metamorphic formations of Essex County may be divided into three groups, (1) the old metamorphic rocks, which are of Cambrian and probably Algonkian age, (2) the serpentine at Lynnfield, and (3) the Merrimack quartzite of Carboniferous age. The only other sedimentary formations are the unconsolidated surficial deposits of Pleistocene and Recent age.

[1] Smith, G. O., The geology of the Perry Basin in southeastern Maine: U. S. Geol. Survey Prof. Paper 35, p. 20, 1905.

[2] Pirsson, L. V., and Washington, H. S., Am. Jour. Sci., 4th ser., vol. 22, p. 514, 1906.

[3] Loughlin, G. F., Intrusive granite and associated metamorphic sediments in southeastern Rhode Island: Am. Jour. Sci., 4th ser., vol. 29, p. 447, 1910.

CAMBRIAN AND ALGONKIAN (?) METAMORPHIC ROCKS.

DISTRIBUTION.

The oldest rocks of Essex County are clearly a series of metamorphic rocks of widely varying composition. They occur only in relatively small areas, usually in the form of elongate lenses entirely surrounded by intrusive granitic rocks, throughout the greater part of the county. The larger areas are shown on the map (Pl. I, in pocket). Small areas occur in Georgetown, Newbury, West Newbury, and Newburyport, the Highfield ridge being composed chiefly of quartz-hornblende schists. Another relatively large area of quartzites, slates, and limestones occurs in Topsfield and northeast of Middleton. Several small patches occur in Lynnfield. A belt of quartzites and slaty schists one-half to 1 mile wide extends southwest from North Saugus across the town of Saugus to Melrose, and from there farther west into Middlesex County. Several rather small areas of "hornfels" occur in North Saugus and in Lynn, and a much larger area extends west from High Rock in Melrose and Wakefield. A few small patches of metamorphic sedimentary rocks occur at Nahant, where, especially at East Point, Lower Cambrian fossils are found. Besides the larger masses, great numbers of small blocks, ranging in size from small inclusions to masses several yards in width and length, occur in the plutonic rocks.

LITHOLOGIC CHARACTER.

Quartzites, slates, and schists.—The metamorphic rocks are of both sedimentary and volcanic origin, although, as in the hornblende schists, it is not everywhere possible to determine the true nature of the original rock. The sedimentary rocks, all highly metamorphosed, range from quartzites to marbles, with many schistose varieties. The quartzites have been entirely recrystallized and are usually fairly coarse grained. However, some of them are extremely fine grained, in fact cherty, and are hard to distinguish from silicified felsites. They are closely associated with slaty beds, usually more or less schistose. On the south side of Breakheart Hill in Saugus a band of knotted schist resembling the knotenschiefer described by Rosenbusch [1] (with quartz knots) is exposed. This schist has been described by Sears.[2] True mica schists are also found.

Marbles and calcareous rocks.—Coarsely crystalline limestones, occurring chiefly in Newbury, contain contact minerals such as wollastonite, garnet, and diopside, which is extensively altered to ser-

[1] Rosenbusch, H., Elemente der Gesteinslehre, p. 97, 1901.

[2] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., p. 113, Salem, Mass., Essex Inst., 1905.

pentine.[1] A calcareous slate at Nahant contains Lower Cambrian fossils. Impure limestones, which are very common, are in many places altered to green massive rocks and grade into hornblende schists, the origin of some of which is thus made evident.

Quartz-hornblende schists.—The dark grayish-green quartz-hornblende schists are banded but usually massive, although some varieties have a poor cleavage. They are completely but finely crystalline. The banding is produced by light and dark minerals in an alternation that in places apparently represents bedding. Quartz and a light-green uralitic hornblende are the chief constituents, but calcite, pyrite, and magnetite also occur, with small quantities of plagioclase feldspar and other minerals.

The quartz-hornblende schists are in many places associated with and in some places apparently grade into feldspar-hornblende schists and amphibolites. It is probable that some of the more basic schists are derived through the metamorphism of ancient basic volcanic rocks, although others seem to be derived through the metamorphism of younger basic plutonic rocks.

"*Hornfels.*"—Metamorphosed basic volcanic rocks are common in the southern part of the county. They are commonly dark to light greenish gray and massive and have been called by most local geologists "hornfels." In many places their amygdaloidal texture and their occurrence as agglomerates clearly show that they are of volcanic origin. They show some intrusive contact relations with the sedimentary rocks, and it is therefore probable that they are in large part of igneous origin.

AGE AND STRUCTURAL RELATIONS.

The metamorphic sedimentary rocks at Nahant are known from good fossil evidence to be of Lower Cambrian age. Sears states that he has found Lower and Middle Cambrian fossils in other parts of the county,[2] but such fossils have not been found by other workers. Yet because the metamorphic rocks are in general similar to those of Nahant they have been generally considered as Cambrian in age, although, as the different patches are completely isolated from one another, it is impossible to tell whether all of them are conformable. It is not probable that any of them are younger than Cambrian, but it is probable that some are pre-Cambrian.

All the metamorphic rocks have been intruded by batholiths of subalkaline rocks, and the isolated metamorphic patches scattered through the county are "roof pendants" in these batholiths. The metamorphic rocks occur also as relatively small inclusions in batholiths of alkaline rocks, which are apparently younger than the subalkaline rocks.

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[1] Clapp, C. H., and Ball, W. G., Econ. Geology, vol. 4, pp. 239-250, 1909.

[2] Sears, J. H., op. cit., pp. 83-84, 1905.

SERPENTINE AT LYNNFIELD.

East of Lynnfield Center is an area of serpentine, which Sears calls an altered peridotite.[1] Crosby in 1876 mapped the rock as an altered limestone.[2] Sears also determined the serpentinized limestone of Newbury as an altered peridotite,[1] but its sedimentary origin is indubitable.[3] The serpentine has on its weathered surface a distinct pattern, as if it were derived from a coarsely crystalline igneous rock. The serpentine appears on microscopic examination to have been derived from either olivine or diopside. If the original mineral were diopside the serpentine may have been derived from the alteration of a contact-metamorphosed limestone. If, on the other hand, olivine were the original mineral the rock may well have been a peridotite. The serpentine shows no contact with the surrounding gabbro-diorite, so that no clue to its origin can be gained from its contact relations. The writer believes that the serpentine was derived from the alteration of a holocrystalline olivine-rich rock, which was older than and was included in the gabbro-diorite.

MERRIMACK QUARTZITE.

DISTRIBUTION.

A wide belt of schistose rocks extends along Merrimack River from the western boundary of the county across nearly its entire width and passes into New Hampshire near Salisbury. These rocks were called the Merrimack group by Hitchcock.[4]

LITHOLOGIC CHARACTER.

In the northeastern part of the belt all of the rocks have a pronounced schistose texture and are in greater part fine-grained phyllites and mica schists. Some are shaly in appearance and many are carbonaceous or graphitic. In places they are massive. In the southwestern part of the belt quartzites are prominent. They are massive, but near their contact with intrusive granite they become foliated and pass into quartz-mica schists.

AGE AND STRUCTURAL RELATIONS.

The Merrimack quartzite has been closely folded, probably into a series of isoclinal folds. The strike of the formation is northeast, ranging ordinarily from N. 30° E. to N. 70° E. The dips are nearly everywhere to the northwest and are usually steep, 50° or more.

In West Newbury and Amesbury the Merrimack quartzite is in contact with the Dedham granodiorite of the subalkaline batholith.

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[1] Sears, J. H., op. cit., p. 133.

[2] Crosby, W. O., Contributions to the geology of eastern Massachusetts: Boston Soc. Nat. Hist. Occasional Papers, No. 3, 1880.

[3] Clapp, C. H., and Ball, W. G., Econ. Geology, vol. 4, pp. 245-247, 1909.

[4] Hitchcock, C. H., Geology of New Hampshire, vol. 2, pp. 621-626, 1877.

The contact is, however, masked by a fault, which hides all clue to the relative ages. Farther west the schist is cut by the Andover granite, which, however, also cuts the subalkaline rocks.

Hitchcock[1] classed the Merrimack as possibly lower Paleozoic. However, it extends to Worcester, Mass., where it is graphitic. Here at the old "coal mine" J. H. Perry[2] found three specimens which were identified by Lesquereux as *Lepidodendron acuminatum*. Although the fossils were not in place, Perry believed that the rock in which they were found was identical with the neighboring schists and on that evidence assigned the schists to the lower Carboniferous. His determination of the Carboniferous age of the rock, which had not been universally accepted, was later substantiated by David White,[3] who in the autumn of 1911 found fossils, regarded by him as probably Pennsylvanian, in place. The Merrimack quartzite, therefore, is classed provisionally as at least as young as the Mississippian.

SURFICIAL DEPOSITS.

The unconsolidated surface deposits are of Tertiary, Pleistocene, and Recent accumulation. They are varied, but by far the most extensive are of glacial origin.

The mantle of glacial drift nearly covers the county. In places, as along the coast from Lynn to Rockport and in the southern part of the county, it is thin, and the underlying bedrock is well exposed. Throughout the central and western parts of the county, from Peabody and Lynnfield north to the Highfield Ridge, which runs from the village of Byfield nearly to Newburyport, the drift cover is very thick and the outcrops are few and relatively small. Still farther north the bedrock is largely drift covered. In the Merrimack Valley, although the glacial deposits are extensive, the outcrops are numerous.

The glacial deposits consist of both stratified and unstratified materials. Sand plains and outwash flats are common. The greater part of the mantle consists of coarse unstratified boulder moraines and large drumlins, with wide stretches of gently rolling or hummock-like hills of ordinary boulder till. Eskers, kames, and other special features are common.

The Recent alluvial deposits consist of wide flats between drift-covered hills. They have been formed by the filling of the old valleys by fine wash from the hills. North of Cape Ann is an almost continuous barrier beach which has been driven back by the waves to a point within 2 to 3 miles of the rocky hills, the intervening space being occupied by a wide salt marsh. Along the principal rivers and valleys occur wide fresh-water marshes, such as Wenham Swamp.

[1] Hitchcock, C. H., Geology of New Hampshire, vol. 2, pp. 621-626, 1877.

[2] Perry, J. H., Note on a fossil coal plant found at the graphite deposit in mica schist at Worcester, Mass.: Am. Jour. Sci., 3d ser., vol. 29, pp. 157-158, 1885.

[3] White, David, Washington Acad. Sci. Jour., vol. 2, pp. 114-118, 1912.

Other special features are the modern beaches and the tie bars or "tombolos," which connect the former islands, such as Nahant and Marblehead Neck, with the mainland.

No attempt has been made to differentiate the different surface deposits. In mapping, the bedrock has been indicated in areas where it is known with assurance and has been left uncolored in areas where it is covered by surficial deposits and is entirely unknown.

IGNEOUS ROCKS.

The igneous rocks, which are described with much more detail in the discussion of the geology of the special area (pp. 36–109), are here, for convenience, subdivided according to their manner of eruption into three classes—subjacent or batholithic rocks, volcanic or effusive rocks, and injected or dike and sill rocks.

SUBJACENT OR BATHOLITHIC ROCKS.

The subjacent rocks of Essex County are subdivided into two main groups, subalkaline and alkaline. The subalkaline rocks are the older and apparently form one great batholith. It is possible, however, that some of those more metamorphosed are still older, although at present they can not be distinguished from the others. The alkaline group is composed of two distinct series of rocks.

SUBALKALINE GROUP.

The rocks of the subalkaline group range from gabbros and gabbro-diorites to granodiorites and even calci-alkaline granites and may be divided into gabbros, gabbro-diorites, gabbro-diorite and amphibolite schists, quartz diorites, and granodiorites.

SALEM GABBRO-DIORITE.

Distribution.—The Salem gabbro-diorite, so called because it occurs extensively and typically in Salem, is the principal rock of the subalkaline batholith. It occurs in Lynn, Salem, Swampscott, and Marblehead, and extends northward in a broad belt through Danvers, Ipswich, and Georgetown to the Highfield Ridge in the southern part of Newburyport. The belt is, however, separated into two parts by a long, narrow, synclinal area, called the Parker River syncline, which is underlain chiefly by granodiorite and volcanic rocks and which extends from the mouth of Parker River to Middleton.

Lithologic character.—The normal Salem gabbro-diorite varies from a fine to a medium grained rock and is commonly gneissic. It is composed chiefly of calcic plagioclase, hornblende, augite or diallage, and biotite, with accessory minerals such as magnetite, ilmenite, pyrite, and apatite. The mafic minerals often form 50 per cent or more of

the rock. The feldspar occurs in euhedral laths, with interstitial dark minerals.

True gneisses are very common. Not only has the original texture of the gabbro-diorite been destroyed during the metamorphism into gneisses, but the minerals have been recrystallized. Hornblende of a green uralitic variety is the chief mafic constituent, although biotite also occurs.

In many places, especially in the central part of the county, the gabbro-diorite has been even more metamorphosed and has been converted into true basic plagioclase-hornblende or amphibolite schists. This is especially true near the intrusive Andover granite and to some extent near the intrusive Quincy granite. Near the schists of Highfield, which are presumably of sedimentary and possibly of volcanic origin, the gabbro-diorite is so schistose that the contact is not everywhere determinable. Possibly some of the amphibolite schists provisionally correlated with and mapped as metamorphosed gabbro-diorite are really older and may be metamorphosed and recrystallized old volcanic or plutonic rocks of Cambrian or pre-Cambrian age. Most of the gabbro-diorite schists, however, have been almost assuredly derived from the Salem gabbro-diorite. They differ lithologically from the gabbro-diorite gneisses only in the extent of foliation and in the separation of the mafic and felsic minerals into distinct lamellae. The plagioclase occurs in small, clear, commonly unstriated grains, and the green uralite in small irregular shreds.

Hybrid varieties of the gabbro-diorite are developed near the intrusive rocks. This development is well exposed near the contacts with the Quincy granite and the syenitic rocks in the southern part of the county and is discussed in considerable detail on pages 39–40. As a rule the hybrid types thus formed are rather local. At the contact with the Andover granite, which contains much more abundant pegmatites and intrusive quartz veins and which therefore seems to have been richer in gases and mineralizers hybridism is extensive, and quartz and biotite enter into the composition of the schists and gneisses. Quartz, feldspar, hornblende, and biotite gneisses formed in this manner are extensively developed in Middleton, Boxford, and Georgetown.

Alteration.—Where not crystallized by regional and contact metamorphism the gabbro-diorite is usually much altered. The hornblende is altering to chlorite; the feldspar is sericitized; and epidote, zoisite, calcite, and other alteration products occur.

Structural relations.—The gabbro-diorite and its allied rocks make up the greater part of the subalkaline batholith, which has been intruded into folded and presumably metamorphosed Cambrian and possibly pre-Cambrian rocks. The intruded rocks which formed the cover of the batholith have been largely removed by erosion and

remain only in a few scattered patches entirely surrounded by the plutonic rocks.

The gabbro-diorite has been intruded by both of the alkaline plutonic granites—the Quincy and the Andover. Other basic dike rocks are intrusive into the gabbro-diorite. However, it is not cut by more felsic rocks of the subalkaline group.

NEWBURYPORT QUARTZ DIORITE.

Distribution.—Quartz diorite occurs in four widely separated areas—in North Saugus; at the southern end of the Parker River syncline, south of the town of Middleton; along the northern and southern borders of the syncline in Newbury, Rowley, Georgetown, and Topsfield; and, most extensively, in Georgetown and Newburyport, extending north through the town of Salisbury to the New Hampshire line. From its occurrence at Newburyport the name Newburyport quartz diorite has been adopted by the United States Geological Survey.

Lithologic character.—The Newburyport quartz diorite is a fairly uniform, medium-grained, somewhat gneissic rock, consisting essentially of plagioclase (andesine-labradorite), orthoclase, quartz, and hornblende, with accessory biotite, augite, ilmenite, magnetite, apatite, rutile, and titanite. It is greatly altered, the plagioclase having been saussuritized and the hornblende largely altered to chlorite. Calcite is also a common secondary mineral and is in many places abundant. By increase in quartz and orthoclase the quartz diorite passes into granodiorite of the Dedham type; and by increase in plagioclase, hornblende, and augite and loss of quartz it passes into gabbro-diorite of the Salem type.

Structural relations.—The Newburyport quartz diorite is one of the normal types of the subalkaline batholith and, though transitional between the Salem gabbro-diorite and the Dedham granodiorite, is of wide distribution and fairly uniform composition. True transitional types to gabbro-diorite on one hand and to granodiorite on the other are known but are rare. The field occurrences of the Newburyport quartz diorite are everywhere closely associated with those of the Dedham granodiorite and the Salem gabbro-diorite and usually occur between them. Many of the actual contacts are faults, as in the Newburyport-Salisbury area and at North Saugus. In some places, however, as north of Parker River in Newbury and as in Topsfield, there appears to be continuous transition between granodiorite and gabbro-diorite, although some minor faults apparently occur.

In its external structural relations the quartz diorite is like the gabbro-diorite and contains inclusions of the Cambrian or pre-Cambrian metamorphics, and at North Saugus it has been invaded by the alkaline Quincy granite.

DEDHAM GRANODIORITE.

Distribution.—The Dedham granodiorite of the subalkaline batholith occurs in Saugus, in Swampscott, and on Marblehead Neck. It is the chief plutonic rock of the Parker River syncline and is well exposed in Topsfield and Middleton. Another large area underlies the western part of Newburyport and parts of the towns of Groveland, West Newbury, Amesbury, and Salisbury. The formation was named [1] for its development at Dedham, in Norfolk County.

Lithologic character.—The Dedham granodiorite is a light-greenish, coarse-grained rock, with a somewhat gneissic texture; and in the Newburyport area is porphyritic, with large plagioclase phenocrysts, 3 to 5 centimeters long. The constituents recognized megascopically are pink feldspar (orthoclase, microcline, and microperthite); white and greenish feldspar (andesine), which is usually in excess over the pink feldspar; abundant quartz; chlorite; epidote; and accessory ilmenite and titanite. The microscope shows that apatite, altered biotite, zoisite, calcite, muscovite, sericite, and leucoxene are also present. The original mafic minerals are indeterminable but are supposed to have been biotite and hornblende. (See also pp. 45–46.)

Although normally the calci-alkaline feldspar is in great excess over the alkaline feldspar, the alkaline feldspar is in great excess in the southern part of the granodiorite area in Saugus near the contact with the Lynn volcanics and in Topsfield and Middleton. The rock in these places is therefore a calci-alkaline granite and is readily distinguished by its red color. It does not occur in sufficient amount, however, to be mapped separately.

Alteration.—The granodiorite has been greatly altered, as is shown by its varied and abundant secondary minerals. It has suffered not only from great dynamic metamorphism but also from deep secular weathering.

Structural relations.—The Dedham granodiorite is clearly comagmatically related to the Salem gabbro-diorite and to the Newburyport quartz diorite. These three main types are connected by transitional rocks; they have the same mineralogic and chemical characteristics; and although they occur close together no one of them cuts any other. All have the same structural relations, being intrusive into the Cambrian and pre-Cambrian(?) metamorphic rocks and being intruded by the alkaline granites. The granodiorite has not been cut by large masses of the Quincy granite, as have the other two types, which have been extensively brecciated. But in Middleton and Topsfield the Dedham granodiorite is cut by a small body of fine-grained alkaline granite, correlated with the Squam granite, which, though younger than the Quincy granite, is closely related to it. Also, north of Parker

[1] Emerson, B. K., Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, p. 175, 1917.

River, in Newbury, the Dedham granodiorite is cut by apophyses of the Andover granite.

Although the porphyritic granodiorite of the Newburyport area is in contact with the Merrimack quartzite in Groveland, West Newbury, and Amesbury the contact is a fault and the relative ages of the two formations are not known.

Resting unconformably upon the subalkaline batholith are the Lynn volcanic rocks. Wherever the unconformable contact is seen the volcanics rest upon the Dedham granodiorite; and the basal agglomerates of the volcanics contain, besides fragments of volcanic and metamorphic rocks, only fragments of the granodiorite. This indicates that only the uppermost zone of the subalkaline batholith was exposed by the prevolcanic erosion and that it was granodiorite. This conclusion is further supported by the fact that the Dedham granodiorite of the Parker River syncline passes outward—that is, downward—in the batholith, through a transitional zone of Newburyport quartz diorite into Salem gabbro-diorite. Also, in several places where contrasted types of the subalkaline rocks are in contact with each other the contacts can be shown to be faults; and in all of such places where the nature of the faulting can be determined the more felsic rock occurs on the downthrown side. It is also probable and in some places is clearly shown that where the volcanic rocks are in contact with gabbro-diorite or quartz diorite, the contact is nearly always a fault. The Dedham granodiorite, therefore, must form the upper portion of the subalkaline batholith and the Salem gabbro-diorite the lower portion, with a zone of Newburyport quartz diorite between.

The subalkaline batholith was intruded by the alkaline batholiths. Its lower rocks, the gabbro-diorite and the quartz diorite, were injected and replaced; but its uppermost rock, the Dedham granodiorite, which at the time of the irruption of the alkaline batholiths occurred at or near the surface of the earth, was not intruded except in relatively few places and then only by the youngest alkaline granites.

ALKALINE GROUP.

The alkaline rocks are of two distinct series. One consists of the Quincy granite with its satellitic intrusions of alkaline and nephelite syenites and of fine-grained and porphyritic granites. The other consists of the Andover granite with its numerous pegmatites and alaskites.

QUINCY GRANITE.

Distribution.—The Quincy granite forms a nearly circular stock in Peabody and Lynnfield and is the chief rock of Cape Ann. It also extends from Beverly to Rockport and north to Ipswich. At Cape

Ann it forms one large continuous batholith, which is, however, nearly divided by the syenite of Beverly and of the Essex Valley and by the area of intrusive granite (Squam granite) with diorite inclusions in the Squam River valley. Small stocks of the Quincy granite occur also in North Lynn, Swampscott, and Marblehead.

Lithologic character.—The Quincy granite is uniform, with definite, fairly persistent characteristics. Its chief constituent is a microperthitic feldspar, which occurs in coarse, rectangular grains. Quartz is interstitial to the larger euhedral feldspars. The mafic minerals are chiefly green katophorite and hedenbergite. Biotite is significant in only a few varieties. Zircon, apatite, and magnetite are minor accessories.

The granite varies from a quartz-rich rock, such as the "Rockport gray" granite (of the trade), with 40 per cent of quartz, to a quartz-poor rock, which is transitional into quartz syenite and nordmarkite. The feldspar averages about 70 per cent, the quartz 25 per cent, and the mafic minerals 5 per cent.

Several minor varieties are chiefly confined to the contact zones. They comprise a porphyritic granite, "fine-grained" granite dikes, and apophyses of aplite and pegmatite, but on account of their small size they can not be properly shown on the geologic map of Essex County.

SQUAM GRANITE.

Along Squam River, which separates the island of Cape Ann from the mainland, a small mass of granite is intrusive into the normal Quincy granite. It is clearly closely related to the Quincy granite but has many minor differences. Its feldspar is chiefly orthoclase, microcline, and albite, rarely intergrown. The little microperthite which is present is irregular, and in it orthoclase greatly predominates over albite. The total feldspar forms only about 35 per cent of the rock, which is correspondingly rich in mafic minerals, quartz forming about 25 per cent, as in the normal granite. The mafic minerals are a green hornblende, similar to the katophorite of the normal granite, and brown biotite. Similar granite occurs at East Danvers and in Middleton and Topsfield and is correlated with the Squam granite. The structural relations of the granite of these areas to the normal Quincy granite are not known, but as the rock is correlated with the Squam granite it is considered to be closely related to Quincy granite, through slightly younger and intrusive into it. All of these varieties occur in contact with the Salem gabbro-diorite and are consequently considered to be satellitic or peripheral masses of the normal Quincy granite and to be analogous to the "fine-grained" granite that cuts the normal type in dikes and is confined largely to the contact.

SYENITIC ROCKS.

Distribution.—The syenitic rocks, which form other contact facies of the Cape Ann batholith, occur in four principal areas—(1) near Beverly and Salem Neck; (2) in a narrow strip along the coast from East Beverly to Manchester harbor; (3) in the valley of Essex River as far northeast as Lanesville on Cape Ann; and (4) from Gloucester to Rockport.

Lithologic character.—The syenitic rocks range from quartz-poor granites to nephelite syenites. The quartz-poor granites, or quartz syenites and nordmarkites, occur chiefly on Cape Ann, and also form a zone between the Quincy granite and the syenites of the Essex River valley. Even the syenites of the Essex River valley are, however, quartz bearing and perhaps are best classed as quartz-poor nordmarkites. The nordmarkites and quartz syenites are identical mineralogically with the normal granite, although of course they contain much more feldspar. Although in the Beverly and Manchester areas nordmarkites are found, the staple rock is a microperthite syenite, pulaskite, or umptekite to which the name Beverly syenite is herein applied. On Salem Neck the nephelite syenite occurs. The nephelite syenite and Beverly syenite are covered by one symbol on the maps accompanying this report. Emerson,[1] however, maps them separately.

The Quincy granite and the syenitic rocks are clearly comagmatically related, as is shown by the predominating and characteristic microperthite and by the presence of the same accessory minerals. The syenitic rocks are confined to the contact zone of the batholith, as is shown by the universal occurrence of inclusions of country rock in the syenite. These rocks are probably marginal differentiates of the alkaline batholith that have crystallized somewhat earlier than the granite, as is shown by the fact that they are most altered near the granite contacts.

ALTERATION OF QUINCY GRANITE AND THE SYENITIC ROCKS.

Although local weathering has taken place the batholiths and stocks of the alkaline Quincy granite and the syenitic rocks are relatively unchanged, not having been foliated or greatly jointed by dynamic metamorphism nor generally altered.

ANDOVER GRANITE.

Distribution.—Intrusive into the Merrimack quartzite two large batholiths of granite, clearly of the same Andover type, one north of Haverhill and the other south of Lawrence, underlie the greater part of the town of Andover and the western part of Essex County.

[1] Emerson, B. K., U. S. Geol. Survey Bull. 597, pl. 10, 1917.

A small stock is intrusive into the Salem gabbro-diorite near the village of Byfield, 6 miles southwest of Newburyport. Other smaller stocks occur in the towns of Georgetown, Boxford, Middleton, and Ipswich. Mingled with the granites and gneisses of the Andover type are gneisses of much greater age.[1] These gneisses have been separated from the Andover granite in detailed mapping and are shown on Emerson's map of Massachusetts.[2] They were not, however, distinguished by the writer, and hence the Andover granite as mapped includes some areas of older gneiss.

Lithologic character.—The normal Andover granite is typically a fairly coarse grained rock consisting of feldspar and abundant quartz (about 35 per cent) with biotite and muscovite as the chief mafic constituents. It is also very commonly gneissic, in places almost schistose. The feldspar is orthoclase, microcline, albite, and some microperthite, and strongly resembles the feldspar of the Squam granite. Some of the quartz grains have been broken; but usually, even where the granite is conspicuously gneissic, they have a clear, sharp extinction, entirely unlike those of the Dedham granodiorite and Newburyport quartz diorite. The biotite is a common brown biotite, and hornblende is virtually absent. In some varieties, as in those near the contact with the Merrimack quartzite, muscovite is the chief major accessory, and these varieties are usually coarser grained than the normal granite and more gneissic.

Accompanying the coarse muscovite granite gneiss and the normal Andover granite are large numbers of pegmatites, similar in composition to the normal granite. They are much coarser grained and far more numerous than the pegmatites which accompany the Quincy granite.

The rocks into which the Andover granite has been intruded are cut by numerous small masses and irregular dikes of an alaskitic granite composed essentially of feldspar and quartz. The feldspar is orthoclase, microcline, and albite. The alaskites are uniformly gneissic and weather red.

Alteration.—Although gneissic and usually more altered than the Quincy granite, the Andover granite is really but slightly altered. The feldspar of the normal muscovite-biotite granite is unclouded, the quartzes have a sharp extinction, and the original mafic minerals are preserved with very little change. This granite is therefore in marked contrast with the somewhat gneissic subalkaline granodiorites and quartz diorites. As the original minerals are unchanged the gneissic texture is doubtless primary and is partly the result of orogenic movement during the intrusion of the granite.

1 Keith, Arthur, personal communication.

2 Emerson, B. K., U. S. Geol. Survey Bull. 597, pl. 10, 1917.

Contact relations.—The Andover granite is clearly intrusive into the Merrimack quartzite of Mississippian or Pennsylvanian age and also into the metamorphosed plutonic rocks of the subalkaline batholith. Not only does it cut the lower or Salem gabbro-diorite zone of the batholith, but its apophysal phases also cut the Newburyport quartz diorite and Dedham granodiorite. The gabbro-diorite has been brecciated by the Andover granite, as well as by the Quincy granite. Extensive exomorphic metamorphism also has taken place, converting the gabbro-diorite gneisses into quartz diorite gneisses containing very large amounts of biotite and uralitic hornblende. This metamorphism is greater than that caused by the intrusion of the Quincy granite and may be due to the fact that the Andover granite was apparently richer in gases, this being inferred from its more abundant pegmatites and from the fact that water enters as an essential constituent into the composition of its mafic minerals.

CORRELATION OF ALKALINE ROCKS.

Although there are no analyses of it the Andover granite is known from its mineral composition and its similarity to the biotite granites of Rhode Island and eastern Connecticut to be distinctly alkaline. Its normal medium-grained biotite type resembles the Squam granite. Also it has been shown to be intrusive into the subalkaline batholith. For these reasons it is correlated with the other alkaline plutonics. From its similarity to the Squam granite, which is slightly younger than the Quincy granite, it may be inferred that the Andover granite also is slightly younger than the Quincy, an inference supported by the normal sequence of irruption of plutonic rocks from mafic to felsic. The only objection to this inference is that the Andover granite is gneissic in character, but, as described above, this is apparently due not to dynamic metamorphism after crystallization but to primary texture. It is probable that the Andover granite was intruded along the axis of greatest orogenic movement in Essex County during the Appalachian revolution, for the Merrimack rocks were then converted into schists, while the crystalline rocks in the southern part of the county were warped only into broad folds. In general, the Andover and Quincy granites were irrupted during one period of batholithic intrusion. One type can not be considered as a satellitic phase of the other, for they were separately irrupted. If both were derived from one parent magma their differentiation must have been deep seated and not "laccolithic," as it doubtless has been in the special marginal phases of each main type.

GABBRO ASSOCIATED WITH DRACUT DIORITE.

Just west of Essex County, in Dracut, there is a stock of gabbro and pyroxenite containing local segregations or impregnations of

pyrrhotite. This stock extends across the boundary of Essex County into the town of Methuen. The gabbro consists essentially of plagioclase (labradorite), pyroxene, a brown hornblende, and biotite. These minerals differ greatly in their relative abundance in the numerous closely related types, which range from feldspathic gabbro or anorthite to a pyroxenite composed of brown, possibly basaltic hornblende and various pyroxenes, augite, diopside, and enstatite. The gabbro is of course subalkaline in character, but it is not related to the other subalkaline rocks, and as there is no available structural data connecting it with them its relations can not be properly discussed at present. Emerson regards it as of late Carboniferous or post-Carboniferous age.

VOLCANIC ROCKS.

LYNN VOLCANICS.

Distribution.—Two areas of effusive volcanic rocks occur in Essex County; one in the southern part, the typical area of the Lynn volcanics, extends westward from Lynn to Middlesex County; and the other, in the northern part, underlies the lower portion of the Parker River basin and extends southward nearly to Topsfield. The northern area was mapped as Newbury volcanic complex by Emerson,[1] who regards the rocks as older than the typical Lynn volcanics.

Lithologic character.—The volcanic rocks of the two areas are similar and were undoubtedly erupted during the same period. They are therefore assigned by the writer to the same formation and called Lynn volcanics. Those of both areas vary considerably in the composition. They are chiefly felsic and were once glassy but are now devitrified and are dense felsites. The principal type of the felsic varieties is a quartz keratophyre, usually reddish, and in some places banded but in other places porphyritic or spherulitic. The phenocrysts are albite and very rarely quartz. The groundmass is essentially feldspathic, although quartz is abundant, the mafic minerals being very small in amount. Volcanic rocks of more mafic composition, apparently interbedded with the normal quartz keratophyres, occur in both the Lynn and Parker River areas. Some of them are trachytes, but the larger number are andesites. As a rule the andesites occur in the upper part of the volcanic series and are more abundant in the Parker River basin than in the Lynn area. They are dark-green rocks, some of them carrying plagioclase feldspar phenocrysts, and are commonly amygdaloidal. The phenocrysts and the feldspars of the groundmass are andesine (about $Ab_{70}An_{30}$). The original mafic minerals have been completely destroyed by alteration, but from the amount of chlorite and epidote now present they must have been abundant.

Fragmental varieties are interbedded with the flow rocks, and at the base of the volcanic formation in both areas is a relatively thick

[1] Emerson, B. K., U. S. Geol. Survey Bull. 597, pl. 10, 1917.

agglomerate, composed of fragments of lava and of the underlying Dedham granodiorite and Cambrian or pre-Cambrian metamorphics. In the Lynn area there are also agglomerates, such as that at Vinegar Hill, which are very coarse, containing heterogeneous fragments, some of which are 15 feet in diameter. It appears as if these agglomerates occupy old volcanic necks, now deeply eroded.

The volcanic rocks, especially the more mafic and less dense varieties, are as a rule a good deal altered. They have been much folded and fractured and in the Lynn area have been silicified and contact-metamorphosed near the Lynn fault and near two minor intrusions of alkaline granite.

Structural relations.—The volcanic rocks were accumulated upon an eroded surface of the subalkaline batholith, very well shown in the Parker River basin. They were subsequently folded into relatively broad folds, along whose limbs considerable faulting took place. Those in the Lynn area are cut by "complementary" dikes of the alkaline granite and even by small intrusive masses of the granite itself; and, according to Metz,[1] those of the Parker River syncline are cut by apophyses of the Andover granite. Being thus related to the alkaline irruptives they must have been formed at the beginning of the second igneous cycle of Essex County.

INJECTED ROCKS.

LACCOLITHS AND SHEETS.

GABBRO AND DIABASE AT NAHANT.

At Nahant the Cambrian quartzites and calcareous rocks have been injected by basic irruptives, consisting chiefly of coarse-grained gabbros and intrusive sheets of diabase.

Lithologic character.—The gabbro, which is normally coarse grained, dark, and in many places greenish, consists essentially of augite, pale gray to pinkish in thin section, and labradorite (about $Ab_{30}An_{70}$). The augite occurs in large grains but is commonly interstitial. Olivine and ilmenite are the most abundant accessory minerals. A biotite of a peculiar orange-brown pleochroism is also present. The irruptive rock varies greatly in composition, grading into a peridotite, consisting of augite, olivine, a brown basaltic hornblende, and biotite. More felsic varieties are also common. The felsic and mafic differentiates in many places lie in thin laminations, forming a banded gabbro similar to that on the island of Skye.[2]

Along the north shore of Big Nahant a felsic differentiate is intrusive into the normal gabbro. It is composed chiefly of microperthite in large euhedral grains and of a small amount of quartz in clear interstitial grains. The original mafic minerals have been altered

[1] Metz, A. C., manuscript thesis, Massachusetts Inst. Tech., p. 32, 1911.
[2] Geikie, Archibald, and Teall, J. J. H., Geol. Soc. London Quart. Jour., vol. 50, pp. 645–659, 1894.

and are now undeterminable but were not abundant. The rock is therefore a quartz syenite.

Intrusive into the folded Cambrian sediments are several large sheets of diabase, which are well exposed at East Point and Little Nahant. The diabase contains olivine and is virtually identical in composition with the normal gabbro but is finer grained and has an ophitic texture.

Structural relations.—Lane[1] has shown that the Cambrian sediments of Nahant have been folded into a syncline and that the gab-

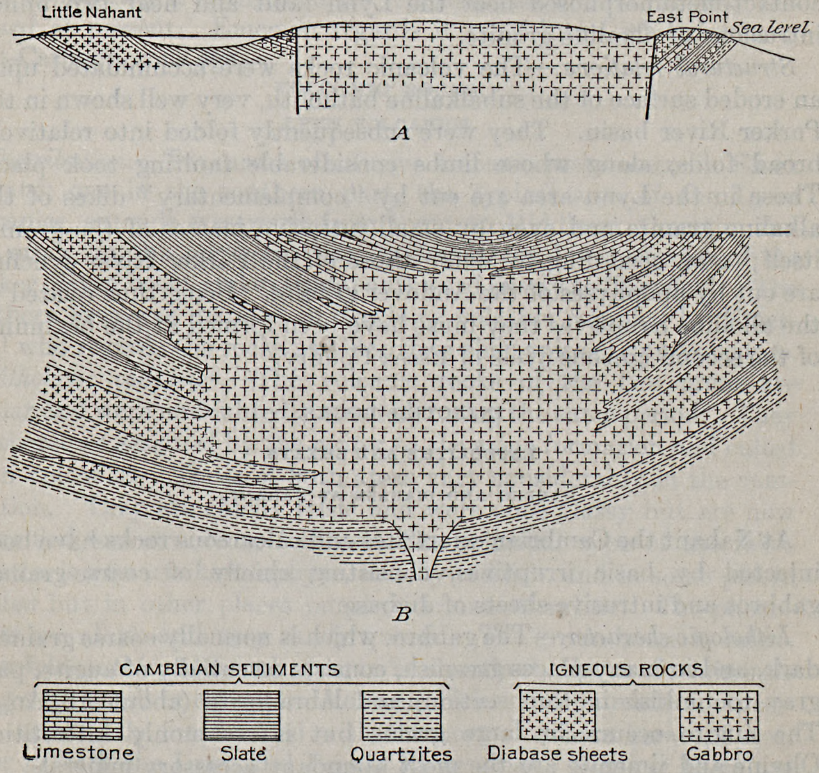

FIGURE 1.—*A*, Structure section from Little Nahant to East Point; *B*, Diagrammatic structure section showing supposed structure, before faulting, of Nahant "cedar-tree" laccolith.

broidal rocks have been injected into the folded sediments as large sheets. He believes the coarse gabbro (diabase) to be a thick sheet, but the writer thinks that the extreme coarseness and differentiation of the central mass is indicative of a more laccolithic or chonolithic shaped body. The intrusive diabase sheets are supposed to be directly connected with the central irruptive mass, although on account of faulting the connection can not be traced at present. (See fig. 1.)

[1] Lane, A. C., manuscript thesis on geology of Nahant, Harvard Univ. Library; also abstract in Boston Soc. Nat. Hist. Proc., vol. 24, p. 91, 1890.

Correlation.—On account of the syenitic and microperthitic differentiate, the occurrence of basaltic hornblende, and of the peculiar orange-brown biotite, the gabbro at Nahant is correlated in a general way with the alkaline batholiths. It has also many points of resemblance with the gabbro associated with the Dracut diorite, which may also be associated with the alkaline irruptives.

DIKES.

A large number of dikes, which it has been impossible to represent on the map (Pl. I), cut the various formations of Essex County. They are chiefly mafic but include some felsic rocks. They are of several periods of injection and may be classified as follows:

1. Diabase dikes, greatly altered, cut the Cambrian formations and the subalkaline rocks.
2. Volcanic dikes, chiefly quartz keratophyres, that cut the Dedham granodiorite in large numbers.
3. Dike rocks related to the alkaline irruptives. Relatively few dikes cut the Andover granite and the surrounding country rock, but large numbers occur in the vicinity of the contacts of the Quincy granite of the Cape Ann and Peabody batholiths.[1] (See Pl. I, in pocket.) Those which accompanied the batholithic intrusion may be subdivided into felsic and mafic dikes, the felsic dikes including quartz porphyries, paisanites, sölvsbergites, and tinguaites, and the mafic dikes including diabases, camptonites, vogesites, kersantites, minettes, and amphibole fourchite.
4. Triassic diabase dikes that cut all the bedrock formations of Essex County in large numbers. These are relatively unaltered diabase dikes which are usually referred to the Newark group.

There are doubtless dikes of types other than those named, for volcanic activity is known to have occurred in eastern New England at several periods, and the feeders for the resulting volcanic rocks should be preserved, even though the effusive forms have long since been eroded.

HISTORICAL GEOLOGY.

The writer's interpretation of the historical and structural geology of Essex County differs from earlier interpretations, in that it recognizes two distinct periods of batholithic intrusion during which unlike rocks, the subalkaline and the alkaline, were irrupted, the former being the older. The subalkaline rocks were intruded into closely folded Cambrian and pre-Cambrian (?) formations at a date which was presumably soon after the formations were deformed during the post-Ordovician Taconic revolution, as it is a well-established principle that batholithic intrusion accompanies or closely follows defor-

[1] Shaler, N. S., Geology of Cape Ann, Mass.: U. S. Geol. Survey Ninth Ann. Rept., pp. 529-611, 1889.

mation. There ensued a long period of erosion during which a large part of the roof of the subalkaline batholith, composed of the deformed and metamorphosed Cambrian and pre-Cambrian (?) formations, was removed and the upper part of the batholith (the Dedham granodiorite) was exposed. In this large roof pendants remained, completely surrounded by the granitic rock.

Upon this old erosion surface, consisting largely of Dedham granodiorite, the Lynn volcanics were accumulated, presumably in Devonian and early Carboniferous time, the eruption being largely of the central type. Possibly during the volcanic period and certainly in early Carboniferous (Mississippian) time sedimentation was in progress in the present Merrimack River basin, and the deposits which now form the Merrimack quartzite were laid down. Both the Lynn volcanics and the Merrimack sediments were folded in middle Carboniferous time, during the period of deformation which initiated the Appalachian revolution. During the Appalachian revolution, which in this region lasted until post-Carboniferous time, the alkaline batholiths were irrupted. The granite of the Cape Ann and Peabody batholiths was apparently irrupted next after the first period of deformation; and the Andover granite, which appears to be younger, was probably irrupted during a later period, presumably in Pennsylvanian time, for the supposed Permian sediments of the Boston Basin, although deformed, are apparently not cut by granitic rocks. Little folding but much faulting apparently took place during the still later periods of deformation.

Probably in Triassic time all the older rocks were cut by large diabase dikes, which, having been injected along fissures, are very numerous in the older, much fractured formations and are comparatively few in the larger, younger, and less fractured batholiths.

STRUCTURE.

On account of the massive character and plutonic origin of most of the rocks of Essex County, their detailed structure can not be determined. It may be that the granitic rocks, especially those of the alkaline type, were irrupted along anticlines. If so, there are two large anticlinal areas, one in the southeastern and the other in the northwestern part of the county, both of which have a general southwest (Appalachian) trend. The Quincy granite was irrupted along the axis of the southeastern anticline and the Andover granite along the axis of the northwestern anticline. Between the supposed anticlinal areas is a wide synclinal area largely underlain by subalkaline rocks. In the central part of this area, along Parker River, a distinct syncline (the Parker River syncline) is composed of Lynn volcanics flanked by Dedham granodiorite, which passes outward through Newburyport quartz diorite into Salem gabbro-diorite. Like the anti-

clines it corresponds in strike with the general Appalachian trend and, as it widens to the northeast, it apparently pitches in that direction. Another large syncline, composed of Merrimack quartzite, occurs along Merrimack River. It also widens to the northeast, where the Dedham granodiorite and the quartz diorite of Newburyport form the southeastern limb. It is probable that the small areas of syenites and of peripheral granites of the main Cape Ann anticlinal area are synclinal also.

Besides the almost innumerable small faults several large ones, both strike and oblique, occur in Essex County. The nature of most of the faults is obscure, but the strike faults are probably reversed and the oblique faults are normal. The faults bounding the southern part of the Parker River syncline, which merge into a single fault to the west and extend parallel to Ipswich River into North Reading, and the faults separating the Merrimack quartzite from the Dedham granodiorite in Groveland and West Newbury, are examples of strike faults.

The oblique faults trend approximately east or north. The Lynn fault, in the southern part of Essex County, trends east across the towns of Saugus and Lynn and probably continues northeastward between the Salem gabbro-diorite and the Dedham granodiorite areas of Phillips Point and Marblehead. Good examples of the northerly faulting occur in West Newbury and Newburyport, where the Dedham granodiorite is separated on the west from the Merrimack quartzite and on the east from the Newburyport quartz diorite.

GEOLOGY OF THE SPECIAL AREA.

METAMORPHIC AND SEDIMENTARY FORMATIONS.

The metamorphic and sedimentary formations have been treated in detail in the discussion of the geology of Essex County as a whole. (See pp. 16–20.) Their distribution in the special area is shown on the map (Pl. II, in pocket). In mapping they have been divided into Carboniferous (Permian ?) rocks, comprising the Cambridge slate of the Boston Basin, and Cambrian and Algonkian (?) rocks, comprising the serpentine at Lynnfield, the "hornfels," and the metamorphic sedimentary rocks.

The metamorphic sedimentary rocks include quartzite, graywacke, calcareous slate, marble, and schist. The "hornfels" are chiefly metamorphosed basic volcanic rocks but may include some injected types and possibly some greatly metamorphosed calcareous sediments. The serpentine at Lynnfield is probably a serpentinized basic olivine dike rock. All these rocks occur in relatively small areas, and all except the serpentine have clearly been intruded by the subalkaline batholith.

The Cambridge slate occurs south of the north boundary fault of the Boston Basin in Malden and Revere. The beds are highly inclined and dip steeply north against the older Dedham granodiorite and Lynn volcanics. They are, therefore, on the downthrow side of the fault.

IGNEOUS ROCKS.

The igneous rocks of the special area may be divided into the two great classes emphasized by all recent petrographers, the subalkaline or calci-alkaline group and the alkaline group.[1] These two groups are distinct both petrographically and structurally. The subalkaline group is the older and will be described first.

SUBALKALINE GROUP.

The subalkaline group contains a complete series of plutonic rocks ranging from granodiorite to a gabbro-diorite. For convenience in description and mapping these have been divided into three main types, which, although fairly distinct, are transitional—the Salem gabbro-diorite, the Newburyport quartz diorite, and the Dedham granodiorite. This series is cut by numerous and large diabase dikes, which are in part older than the alkaline magma and which may be related to the subalkaline plutonics.

SALEM GABBRO-DIORITE.

DISTRIBUTION.

The Salem gabbro-diorite underlies more than half of the special area. (See Pl. II, in pocket.) It is typically developed in the towns of Salem, Marblehead, Lynnfield, and Wakefield. Beyond the area it extends north in a wide belt nearly to Newburyport and west more or less continuously to Waltham and Weston. In Swampscott and Lynn its southern boundary is the Lynn fault, which separates the Lynn volcanics from the crystalline rocks to the north. In the western part of the area, in the towns of Saugus and Wakefield, it is transitional southward into quartz diorite, which lies immediately north of the westward extension of the Lynn fault.

Although continuous around the individual masses, the gabbro-diorite is interrupted by the Peabody and Marblehead stocks of alkaline Quincy granite and by smaller bosses in Swampscott and Lynn. In the neighborhood of the intrusive granites it is irregularly veined with granite, and its actual contact is ordinarily marked by a wide zone of breccia in which either the gabbro-diorite or the granite may predominate.

Besides these interruptions it entirely surrounds many small patches of metamorphosed sedimentary rocks, and in Lynnfield it surrounds a small area of serpentine.

[1] Harker, Alfred, The natural history of igneous rocks, p. 90, 1909.

Over a larger part of the area the outcrops are abundant, and the boundaries of the gabbro-diorite may be mapped with a great deal of assurance. In the northern and western parts of the area the drift cover is thick and the outcrops are few, but the granite-diorite contact is located accurately. There are doubtless several areas of metamorphic sediments in Lynnfield not shown on the map, and the boundaries of those shown are only approximate.

LITHOLOGIC CHARACTER.

The formation is typically a fairly uniform gabbro-diorite, but it has many variations, which are due to three principal causes—differentiation of the magma from which the gabbro-diorite crystallized; dynamic metamorphism and secular decay; and contact metamorphism.

Normal rock.—The normal rock is dark, fine to medium grained, and consists of plagioclase, hornblende, and biotite. In many specimens accessory pyrite and magnetite are abundant.

Under the microscope the essential minerals are seen to be labradorite-andesine, pyroxene (a colorless augite or diallage), common green hornblende, and brown biotite. The accessory minerals are olivine (absent in many specimens), orthoclase (in some specimens), and apatite, magnetite, and pyrite. The texture is subhedral and often poikilitic, some of the lath-shaped plagioclase feldspars being included in the hornblende or biotite and even in the pyroxene. Orthoclase, if present, is invariably interstitial. The plagioclase varies in composition as is shown by the wavy extinction of its 010 face, although it rarely shows marked zonal structure. Its composition appears to be chiefly labradorite ($Ab_{40}An_{60}$) but ranges to andesine ($Ab_{65}An_{35}$). The feldspar normally makes up about 50 per cent of the rock. Pyroxene, hornblende, and biotite are in about equal amounts. The pyroxene was apparently the first mineral to form, and the hornblende and biotite surround it, in some specimens being clearly derived from it. Both of these minerals occur also in sharply defined although rarely euhedral grains and are therefore probably in part original. In most varieties the alteration is marked, but in some a little sericite in the feldspars is the only alteration product.

Variations.—Some of the varieties of the normal gabbro-diorite are somewhat lighter colored, on account of a larger percentage of feldspar and also on account of their coarser grain. Some of the coarse-grained varieties are probably in part recrystallized, and in these large crystals of apparently secondary biotite occur. The pyroxene of the siliceous varieties is usually a light-greenish diallage with characteristic schiller structure, the inclusions being biotite and magnetite or ilmenite. It has no distinct pleochroism, and the

extinction angle is more than 40°, so that it is probably aluminous. As in the normal gabbro-diorite, the diallage is altered to common green hornblende to such an extent that virtually all the pyroxene grains are rimmed with hornblende. Considerable hornblende is, therefore, present, and much of it includes a fine magnetite dust as well as larger grains of magnetite. Brown biotite with a strong absorption is abundant, and as it is included in both the hornblende and pyroxene, it may be in part original.

Some still more siliceous varieties found in North Lynn and Wakefield contain quartz and orthoclase and are transitional into quartz diorite. The transition zone is narrow, and the normal gabbro-diorite grades rapidly to quartz diorite. Quartz and orthoclase occur in the interstices of the other minerals and exceptionally inclose them. The orthoclase is pink on the weathered surface. The plagioclase of these varieties shows a marked zonal growth, varying in composition from calcic andesine to sodic oligoclase. In these siliceous varieties the hornblende is more abundant than the pyroxene, and biotite occurs only in small quantities and is not even a common secondary mineral.

Less commonly, more basic differentiates of the normal gabbro-diorite occur. In Salem there is a coarse-grained basic variety of high specific gravity, and even in the hand specimen the dark mineral is seen to be chiefly pyroxene. The feldspar is a calcic labradorite ($Ab_{30}An_{70}$), with no evidence of a more sodic phase. Diallage, which is the chief mafic mineral, occurs in large grains and incloses the feldspar developing an ophitic texture. Olivine is present in considerable amount, about 5 per cent, but hornblende is low. Biotite is secondary, surrounding the olivine and magnetite. The hornblende has a greenish to brown pleochroism suggestive of the basaltic hornblendes of the contact zone but has a high extinction angle, 27°, and may be katophorite. This rock is a fairly typical olivine-bearing gabbro.

Another phase of the gabbro-diorite is a porphyritic diorite which occurs in North Salem and Swampscott. It is apparently not related to the porphyritic diorite from Bass Rock, Cape Ann, described by Washington.[1] It is a dark greenish-gray rock with a medium-grained groundmass of feldspar and hornblende and large and moderately abundant (dopatic) phenocrysts of feldspar. Its essential minerals are plagioclase and common green hornblende, with accessory augite and magnetite. The rock is greatly altered; only the central portions of the feldspar grains are replaced by sericite and epidote, leaving their margins unaltered, but the mafic minerals are almost completely replaced by uralite and chlorite.

[1] Washington, H. S., Jour. Geology, vol. 7, pp. 61–62, 1899.

Alteration.—Although comparatively unaltered rocks are found, the greater part of the gabbro-diorite has been so profoundly altered that in many specimens its sheared and altered nature is evident even megascopically. The plagioclase has altered in its characteristic manner to sericite and calcite. Little of the original light-green diallage or augite remains, both having gone over to hornblende and biotite. The hornblende is the more abundant and surrounds the pyroxene. The olivine has almost completely altered to serpentine, and even the magnetite is apparently partly replaced by biotite, a change also noted by Washington.[1] The biotite and hornblende also are altering to uralite and chlorite. Apparently the first change in the hornblende is a loss of its color and of its strong pleochroism. This is followed by the final change to uralite or chlorite.

In some of the phases dynamic metamorphism as well as secular decay has taken place and the rock has been converted into a gneiss and even a schist. Conversion into schists, although common in Essex County, has not been observed in the special area. In the gneissic phases the feldspar is broken and is penetrated by secondary hornblende. Some of it has been crushed and recrystallized into small clear grains. Either the polysynthetic twinning of the original grains has been partly destroyed, or they have been surrounded by a rim of sodic plagioclase (untwinned albite-oligoclase).[2] The hornblende has developed twinning. Saussurite, sericite, and a streaky brown mica occur, as well as the other secondary products mentioned above.

The schistose variety is dark and is composed chiefly of hornblende with feldspathic streaks, some of which are apparently veinlets of the intruding granite. The minerals occur in small anhedra with the overlapping grains arranged in parallel bands. The essential minerals are plagioclase, hornblende, and biotite, with accessory augite and magnetite, and all are evidently recrystallized.

Contact metamorphism and hybridism.—Near the contact with the intrusive Quincy granite and in the breccia zone the Salem gabbro-diorite has been recrystallized and has been penetrated by materials from the invading magma. Also, the gabbro-diorite has been partly assimilated by the molten magma, thus producing true hybrid types.

Where there has been no introduction of foreign material the original mineral composition has been largely preserved. Megascopically the rock resembles the ordinary gabbro-diorite but seems much less altered; and on microscopic examination it shows little of such typical alteration products as sericite and epidote, for the rock seems to have been restored by recrystallization to nearly its original

[1] Jour. Geology, vol. 7, p. 60, 1899.
[2] Wolff, J. E., U. S. Geol. Survey Bull. 150, p. 326, 1898. Untwinned albite in albite schist.

mineral composition. The feldspar in the recrystallized rock is still plagioclase, ranging from labradorite to andesine. Although the twinning is preserved in many places, it is commonly much less pronounced than in the original grains. Amphibole, the most abundant mafic mineral, is in part derived from the original pyroxene. It occurs chiefly as olive-green hornblende but also as uralite, and, chiefly in the breccia zone, as brown basaltic hornblende.[1] A brown biotite apparently identical with that in the normal rock is abundant. The pyroxene is chiefly augite but some of it is diallage. It is ordinarily surrounded by hornblende. In some specimens olivine occurs. Magnetite and apatite are present in the usual minor amounts.

In many parts of the contact zone the rock is recrystallized so as to have a very coarse grain and has developed large poikilitic basaltic hornblendes and biotites. Some of the coarsely recrystallized gabbro-diorites are notably feldspathic, the best-exposed occurrences being on Salem Neck, where the intrusive rock is syenite. Near the granite contacts both quartz and microperthite appear in the gabbro-diorite, and where the gabbro-diorite is intruded by nephelite syenite on Salem Neck nephelite has apparently impregnated the older rock.

CHEMISTRY AND CLASSIFICATION.

The table below gives the available analyses of the Salem gabbro-diorite.

Analyses of Salem gabbro-diorite and composition of average gabbro.

	1	2	3	4
SiO_2	49.84	51.82	45.32	49.50
Al_2O_3	17.45	17.06	18.99	18.00
Fe_2O_3	1.64	1.97	3.78	2.80
FeO	9.43	8.60	9.78	5.80
MgO	4.77	4.87	4.68	6.62
CaO	8.34	8.59	9.19	10.64
Na_2O	3.90	3.44	3.78	2.82
K_2O	1.35	1.77	2.12	.98
H_2O+	.54	.20	.31	1.60
H_2O-	.26	.11	.09	
CO_2	None.			
TiO_2	1.56	2.15	1.94	.84
P_2O_5	.10			.28
MnO	.15			.12
BaO	Trace.			
SrO	Trace.			
S	.12			
	99.45	100.58	99.98	100.01
Specific gravity	3.090		2.975	

1. Gabbro-diorite, railroad cut, east of Montrose station, Lynnfield, Mass. M. F. Connor, analyst. Washington, H. S., U. S. Geol. Survey Prof. Paper 99, pp. 480-481, 1917.
2. Diorite, Peache Point, Marblehead, Mass. H. S. Washington, analyst. Jour. Geology, vol. 7, p. 60, 1899.
3. Hornblende gabbro, Salem Neck, Mass. H. S. Washington, analyst. Jour. Geology, vol. 7, p. 63, 1899.
4. Average gabbro, excluding olivine gabbro. Daly, R. A., Average composition of igneous rocks: Am. Acad. Arts and Sci. Proc., vol. 45, p. 225, 1910.

[1] Washington, H. S., Jour. Geology, vol. 7, p. 56, 1899.

The norms of rocks 1, 2, and 3 are as follows:

Norms of Salem gabbro-diorite.

1[a]		2[a]		3[b]	
Or 8.34	Di 12.25	Or 10.56	Di 13.98	Or 12.79	Di 14.25
Ab 31.44	Ol 14.69	Ab 29.34	Hy 8.36	Ab 12.84	Ol 12.06
An 25.85	Mt 2.32	An 25.58	Ol 5.59	An 28.36	Mt 5.34
Ne .85	Il 3.04		Mt 2.78	Ne 11.64	Il 3.65
	Ap .34		Il 4.10		
Class II″, order 5, rang 3, subrang 4. Femic, andose.		Class II (III), order 5, rang 3, subrang 4. Camptonose-andose.		Class II (III)″, order 6, rang 3, subrang 4. Extremely femic, andose-salemose.	

[a] Calculated by H. S. Washington (U. S. Geol. Survey Prof. Paper 99, p. 481, 1917).
[b] Idem, p. 575.

Rocks 1 and 2 are seen to be of very similar composition. Rock 3 is somewhat similar to these, falling into the same class, rang, and subrang but into a different though transitional order on account of the larger percentage of nephelite in its norm, owing to the decrease in silica and the increase in potash. This peculiar change in such a basic rock is due to the contact metamorphism of the gabbro-diorite in the nephelite syenite breccia zone of Salem Neck.

The Salem gabbro-diorite differs from the average gabbro chiefly in having higher ferrous iron and alkalies and lower magnesia and lime. These differences are caused by its larger percentage of hornblende and its content of more alkaline feldspars. It is, therefore, not a true gabbro but is transitional into a diorite. The distinction made between gabbro and diorite by Rosenbusch,[1] Brögger,[2] and Iddings[3] is based chiefly on the alkalinity of the feldspar, although they recognize the preponderance of pyroxene in gabbro and of amphibole in diorite. The dividing point in the feldspar, although not stated definitely by these authors, is virtually Ab_1An_1. In the Salem gabbro-diorite the feldspar ranges to either side of this dividing point, although it is usually more calcic. Both pyroxene and amphibole are present, the amphibole doubtless in part primary, although pyroxene may have been in excess in the original rock. Therefore, though the rock has strong affinities with gabbro, it is also allied to diorite and is classed as a gabbro-diorite. This use of the term is very different from that of Williams.[4] To use a combination of the names of two primary "rock families" to designate an altered rock is, however, hardly logical. The presence of pyroxene or amphibole is no longer held by the majority of petrographers, including those noted above, to be the basis of the distinction between the two families. In whatever manner the term gabbro-diorite is defined it at least

[1] Rosenbusch, H., Elemente der Gesteinslehre, pp. 137–139, 150–151, 1901.
[2] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, vol. 1, p. 93, 1894; vol. 2, p. 35, 1895.
[3] Iddings, J. P., Igneous rocks, vol. 1, p. 348, 1909.
[4] Williams, G. H., U. S. Geol. Survey Bull. 28, p. 27, 1886.

always connotes a rock intermediate between a gabbro and a diorite and has been used in this sense,[1] although not widely. With this meaning, which seems the most logical and convenient, the term has been employed in this report.

Washington's description of the Salem gabbro-diorite[2] is misleading in some particulars, for he describes the rock only from a small area where it has been profoundly altered by contact metamorphism. The gabbro-diorites or diorites are not essentially monzonitic. That the siliceous phases approach the akerites (the nordmarkites and quartz syenites of this report) is true only in the sense that the siliceous phases he has in mind are hybrid types between the diorite and the syenite and are not siliceous differentiates. The quartz and microperthite which he describes[3] as occurring in the rock occur in it nowhere except near the granite contacts and are surely secondary. The rock from Peache Point which he analyzed is, however, a typical example of the gabbro-diorite. The "hyperitic" diorite or hornblende gabbro from Salem Neck that he described and analyzed and the hyperitic essexite are both contact-metamorphosed phases of the basic gabbro-diorite (the olivine-bearing gabbro) which is characteristic of Salem Neck.

NEWBURYPORT QUARTZ DIORITE.

The name Newburyport quartz diorite has been adopted by the United States Geological Survey for the rock of the subalkaline group intermediate in composition between the Salem gabbro-diorite and the Dedham granodiorite into both of which types it is transitional. It is extensively developed in North Saugus and Newburyport.

DISTRIBUTION.

The Newburyport quartz diorite occurs north of the Lynn fault and underlies a belt extending from Lynn Woods across North Saugus to Wakefield. The belt is comparatively narrow, its maximum width being about 1 mile. The quartz diorite is transitional into gabbro-diorite on the north and also on the south, just west of Birch Pond, Lynn, where the gabbro-diorite lies immediately north of the Lynn fault. In the central part of the main anticlinal area of the Dedham granodiorite in Saugus some quartz diorite which is transitional into the granodiorite is coarser grained and more quartzose than normal. A similar quartz diorite is found also in the Melrose-Malden anticline of granodiorite.

The quartz diorite is not continuous northward, although small areas occur in the Parker River syncline and a larger area at Newburyport.

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[1] Kemp, J. F., Handbook of rocks, p. 188, 1904. Lord, E. C. E., Am. Geologist, vol. 26, p. 340, 1900.

[2] Jour. Geology, vol. 7, pp. 57-60, pp. 63-64, 1899.

[3] Idem, p. 59.

LITHOLOGIC CHARACTER.

The formation is typically an orthoclase-bearing quartz diorite but ranges from a normal quartz diorite to a basic granodiorite. Monzonite facies also occur.

Macroscopically the normal rock is of medium grain and carries greenish-black hornblendes sharply delimited against feldspar and quartz. The feldspar is of two kinds, white to light-greenish weathering plagioclase and pinkish-weathering orthoclase. The quartz is abundant. Small basic schlieren or segregations are common in some specimens but are rounded and never angular.

Under the microscope the essential minerals are seen to be andesine ($Ab_{60}An_{40}$), quartz, and common green hornblende. The accessories are orthoclase, with titanite, apatite, and magnetite as minor accessories. Traces of augite or diallage also have been noted in the Newburyport rock, and doubtless some of the hornblende or uralite in it is of secondary origin. The texture is subhedral with euhedral andesine and hornblende and interstitial quartz and orthoclase. As the rock normally contains less than 8 per cent of orthoclase it is best classed as a quartz diorite.[1] The quartz is, however, high for normal quartz diorite, ranging from 15 to 20 per cent. The amounts of andesine and hornblende and perhaps originally of augite are normal, andesine forming 50 to 60 per cent of the rock and hornblende and augite 20 per cent.

The quartz diorite is greatly altered, the secondary minerals being numerous and abundant. The andesine is greatly altered, being clouded with sericite, epidote, and calcite, but the orthoclase is comparatively clear. If augite was originally present all traces of it have disappeared in most specimens. Hornblende, and augite if present, have for the greater part been broken and altered to aggregates of biotite and muscovite, pale-green uralite, and a little chlorite.

The quartzose varieties of the quartz diorite are distinctly coarse, although not so coarse as the Dedham granodiorite, the average diameter of the grains being 4 to 5 millimeters. Orthoclase is more abundant than in the normal quartz diorite, although it probably nowhere exceeds 8 per cent, but in many specimens it occurs in euhedral grains. These quartzose varieties are not abundant, as the quartz diorite passes rapidly into the typical granodiorite of the Dedham type. In the western part of the area, in the town of Wakefield, where the quartz diorite is in contact with hornfels, quartz is low, but feldspar, both andesine and orthoclase, is high, so that there the rock passes into a monzonitic facies.

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[1] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, p. 277, 1900.

Owing to the lack of pink-weathering orthoclase and an increase in the dark minerals, the more common basic varieties are darker and more basic looking than the normal rock. Orthoclase, however, is usually present although in small amount. Quartz occurs in its normal percentage. In the change from the Salem gabbro-diorite, through the Newburyport quartz diorite, to the Dedham granodiorite, orthoclase first enters as an accessory in the interstices between the euhedral grains of plagioclase and does not become significant until the felsic end of the quartz diorites is reached. Quartz, on the other hand, rapidly increases in amount, so that the change from gabbro-diorite to quartz diorite is abrupt.

The quartz diorite is commonly not only altered but is in many places much sheared. The shear planes are slickensided and the rock is cut by veinlets of calcite and epidote. Sheared phases occur in the Lynn Woods south of Walden Pond.

On microscopic examination it is seen that the original feldspathic minerals have been broken into granular aggregates of feldspar and have been recrystallized to some extent. The alteration products are chiefly epidote and calcite, both of which minerals occur as small anhedra and as minute veinlets. All of the original mafic minerals have gone over to chlorite.

The Newburyport quartz diorite is the quartz-augite diorite of Sears and Washington. Washington suggests that the rock approaches the nordmarkites in composition.[1] But both structurally and mineralogically it is very different, although a part of the area mapped by Sears as nordmarkite is considered by the writer to be occupied by diorites and hybrid rocks between diorite and granite. Although no chemical analysis has been made it is clear from the mineralogic character and from comparison with the analysis of the Dedham granodiorite that the quartz diorite is much richer in lime and magnesia and correspondingly poorer in silica, alumina, and potash than the nordmarkite analyzed by Washington.[2]

DEDHAM GRANODIORITE.

DISTRIBUTION.

The most felsic of the subalkaline rocks is a granodiorite called the Dedham granodiorite, from its extensive development in the town of Dedham. In the special area it occurs only south and east of the Lynn fault, where it is exposed in several relatively small anticlinal areas. The largest of these areas extends from east Melrose through the town of Saugus to Birch Pond. Two other

[1] Washington, H. S., Jour. Geology, vol. 7, p. 61, 1899.
[2] Idem, vol. 6, p. 800, 1898.

anticlines occur farther south, one in north Malden and south Melrose and the other in northeast Malden, near the village of Maplewood. All these anticlinal areas are nearly surrounded by the Lynn volcanics, which rest unconformably on the Dedham granodiorite. There are two other areas, one in the town of Swampscott, on Phillips Point, and the other on Marblehead Neck.

To the west of the special area the Dedham granodiorite occurs in Middlesex County, and to the north it is well developed in the neighborhood of Rowley and Newburyport. Small areas occur in Middleton and Topsfield also.

LITHOLOGIC CHARACTER.

Megascopically the Dedham granodiorite is a light-colored coarse-grained subhedral rock, more or less gneissic, consisting essentially of feldspar, quartz, and dark minerals. Some varieties are typical gneisses, but their mineral composition is the same as that of the normal rock. In places the texture is porphyritic, the plagioclase occurring as large euhedral grains. The typical porphyritic variety is rare in the special area but is abundant in Newburyport. The feldspar is of two varieties—plagioclase and orthoclase—which are easily distinguished megascopically by their characteristic weathering, the plagioclase altering to light green and the orthoclase to pink or red. Quartz is prominent, occurring in large, irregular grains. Chlorite is the principal dark constituent. Epidote is everywhere present and in many specimens is very abundant. Magnetite and pyrite are recognizable minor accessories.

Microscopically the essential minerals in the normal rock are seen to be microcline or orthoclase, and in the more felsic varieties microperthite, andesine ($Ab_{65}An_{35}$), quartz, and originally probably both hornblende and biotite. The accessory minerals are magnetite, ilmenite, titanite, and apatite. The secondary minerals include chlorite, clinochlore, epidote, zoisite, calcite, muscovite, sericite, rutile (?), leucoxene, pyrite, and kaolin.

The chief feldspar is the andesine. It has been subject to great strain, for some of it has been broken. But more commonly it has been distorted, as is shown by the distorted twinning lamellae. It is altering to sericite, and also has furnished part of the material of the comparatively coarse granular aggregates of epidote, zoisite, and calcite.

The potash feldspar is largely microcline. It is not abundant, forming only about 10 per cent of the rock. It is usually interstitial but in some places occurs in large euhedral grains. In the felsic varieties of the granodiorite, which are true granites, well developed

in Saugus near the contact with the overlying volcanic rocks, considerable microperthite enters the composition of the rock and is the chief alkaline feldspar. The microperthite consists of an irregular intergrowth of orthoclase or soda orthoclase with albite or a more calcic plagioclase. The orthoclase forms fully 75 per cent of the microperthite and is much more altered than the albite, being greatly kaolinized.

Quartz is interstitial and has been fractured and strained by dynamic metamorphism.

Chlorite is the most abundant mafic mineral and is for the greater part interlaminated with a brownish-green micaceous mineral, probably clinochlore. It is therefore probable that biotite was originally present. However, from the shape and occurrence of most of the chlorite, especially well seen in the polished specimen, the chlorite seems to have been largely derived from hornblende. The prevalence of hornblende in the consanguineous Newburyport quartz diorite, as well as the chemical composition of the rock, makes this conclusion almost certain.

Titanite was probably originally present but has apparently altered to a uniaxial mineral, presumably rutile. In the Newburyport quartz diorite this same mineral shows the cross twinning of rutile and includes feldspar. As original rutile would ordinarily crystallize before feldspar it is probable that this mineral, doubtless rutile, is secondary after titanite.

Magnetite and ilmenite must both be present, for there is more of the black metallic mineral than can be accounted for by the 0.50 per cent of titanium oxide shown in the chemical analysis. Virtually all of the black metallic mineral is, however, surrounded by a thick, irregular rim of leucoxene.

FELSIC INTRUSIONS.

At the crossing of the Newburyport turnpike and the Wakefield road, a mile west of Saugus village, two very siliceous inclusions, one 10 by 15 inches and the other 12 by 4 feet, occur in the Dedham granodiorite. The included rock has a much larger percentage of alkaline feldspar than the normal granodiorite and a very small percentage of mafic minerals, and it is therefore a granite. These included fragments are subangular. It is hardly probable that they are segregations, for no similar segregations are known in the Dedham granodiorite. Rather they are cognate xenoliths.[1]

[1] Harker, Alfred, The natural history of igneous rocks, p. 336, 1909.

CHEMISTRY AND CLASSIFICATION.

The chemical composition of the Dedham granodiorite is shown in the following analyses:

Analysis of Dedham granodiorite, average composition of granite and granodiorite, and limits of variation of granodiorite.

	1	2	3	4	5
SiO_2	68.94	69.92	59 -68.5	65	65.10
Al_2O_3	14.11	14.78	14 -17	16	15.82
Fe_2O_3	1.68	1.62	1.5- 2.5	1.50	1.64
FeO	2.88	1.67	1.5- 4.5	3	2.66
MgO	.80	.97	1 - 2.5	2	2.17
CaO	4.62	2.07	3 - 6.5	5	4.66
Na_2O	3.53	3.28	2.5- 4.5	3.50	3.82
K_2O	2.41	4.07	1.5- 3.5	2.25	2.29
H_2O+	1.13	.78	....	1.75	1.09
H_2O-	.22	....	....		....
TiO_2	.50	.39	....		.54
P_2O_5	.08	.24	....		.16
MnO	.05	.13	....		.05
BaO	.04	.06	....		....
	100.99	100.00	....	100.00	100.00
Specific gravity	2.723	....	....	....	....

1. Dedham granodiorite. Old quarry, a mile west of Saugus railroad station, Mass. M. F. Connor, analyst. Washington, H. S., U. S. Geol. Survey Prof. Paper 99, pp. 252–253, 1917.
2. Average of all granites. Daly, R. A., Average chemical composition of igneous rock types: Am. Acad. Arts and Sci. Proc., vol. 45, p. 219, 1910.
3. Lindgren, Waldemar, Limits of variation of granodiorite: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 35, 1896.
4. Average composition of granodiorite. Idem.
5. Average composition of granodiorite. Daly, R. A., op. cit., p. 223.

The original mode of the rock can not be satisfactorily worked out, either by the Rosiwal method or by calculation from the chemical composition, on account of its altered nature and the uncertainty of its original alferric minerals. By a combination of the two methods the following mode has been calculated, which is probably accurate within 4 to 5 per cent for each constituent:

Mode of Dedham granodiorite.

Quartz	36
Andesine (Ab_2An_1)	41
Orthoclase	10
Alferric minerals	11
Magnetite	.5
Ilmenite	.5
Titanite	.7
Apatite	.1
	99.8

The norm of the Dedham granodiorite, which has been calculated from the analysis, is as follows:

Norm of Dedham granodiorite.[1]

Quartz	28.56	Diopside	6.07
Orthoclase	14.46	Hypersthene	1.99
Albite	29.34	Ilmenite	.91
Anorthite	15.57	Magnetite	2.55

Class I (II), order ″4, rang ″3, subrang ″4. Quaric, alkalic tonalose-yellowstonose.

From the description and tables given above it is seen that the Dedham granodiorite is more femic than the average granite calculated by Daly, being much higher in lime and lower in potash, although the amount of silica is virtually the same. Furthermore, though the Dedham granodiorite does not contain more ferric oxide, Fe_2O_3, and magnesia, Mg_2O, than the average granite, it contains considerably more ferrous oxide, FeO. It is seen that the Dedham granodiorite, as compared with both Lindgren's and Daly's average granodiorites, is higher in silica and to a slight extent higher in potash and is distinctly lower in magnesia. However, all the oxides except silica fall within the limits given by Lindgren for granodiorite, and, as he has pointed out, the family of granodiorites includes acidic (quartzose) types, with over 69 per cent of silica.[2] It is also seen that the mode of the rock corresponds with that given by Lindgren [3] for the average granodiorite, although quartz is much higher. The rock is best classed, therefore, as a quartz-rich granodiorite.

ALTERATION AND METAMORPHISM.

The Dedham granodiorite, as already stated, has been greatly altered by dynamic metamorphism and by deep secular weathering. In this last respect it differs from the Salem gabbro-diorite and to a less extent from the Newburyport quartz diorite. The alteration products which are probably the result of the weathering are epidote, zoisite, calcite, and kaolin.

The granodiorite has also been sheared and fractured and converted into gneiss. In or near shear zones in the granodiorite, well shown at Phillips Point, there are numerous veins of quartz and epidote. In addition, the granodiorite has been cut by granite aplite, diabase, and volcanic dikes that have still further altered it.

APLITES.

There are but few aplite dikes which can be definitely correlated with the Dedham granodiorite. However, at Phillips Point, Swamp-

[1] Washington, H. S., U. S. Geol. Survey Prof. Paper 99, p. 253, 1917.
[2] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, p. 277, 1900.
[3] Idem, pp. 277, 282.

scott, there are some cutting the granodiorite that are apparently related to the subalkaline rocks.

The aplites are light-pink holocrystalline fine-grained rocks that consist of feldspar and quartz, with a little chlorite and magnetite. On microscopic examination the essential minerals are seen to be microcline, oligoclase ($Ab_{75}An_{25}$), and quartz. The only primary accessory is magnetite. The secondary minerals are sericite, kaolin, and chlorite. The oligoclase, microcline, and quartz occur in about equal amounts in closely locked anhedra, although much of the quartz includes grains of feldspar. The accessories are only about 2 per cent, a few shreds of chlorite representing the original mafic constituent. The alteration is not great, although the rock shows evidence of strain and the oligoclase has been sericitized.

BASIC DIKES.

The subalkaline rocks are everywhere cut by numerous diabase dikes, which vary in size from very small to very large—over 100 feet in width. Some are known to be older than the alkaline batholith, for they are cut by apophyses of Quincy granite—as, for example, a badly faulted dike just west of the Newburyport turnpike, half a mile south of Hawkes Pond, in North Saugus. However, it has been impossible to distinguish the diabase dikes of different ages, and they are described together. (See pp. 94–97.) It is possible that some are related to the subalkaline rocks, cutting them according to the normal sequence of eruption.

So far as known all the dikes that are possibly related to the subalkaline rocks are normal diabase. They have been greatly altered and contain but little of the original augite, most of which has gone over to hornblende. The plagioclase is saussuritized and is not determinable. As far as could be detected olivine is rare. Magnetite is, however, abundant.

MAGMATIC RELATIONS.

The rocks of the subalkaline group are almost certainly magmatically related and from their structural relations apparently make up one large batholith. Most of the rock of this batholith is gabbro-diorite, and it is one of the largest batholiths known of such a basic composition. The comagmatic origin of the subalkaline rocks is well shown by certain peculiarities which can be traced throughout the group. The rocks are all rich in ferrous iron, and the more salic are comparatively high in lime. In all of them soda exceeds potash. Titanium, occurring in ilmenite, titanite, and rutile, is high. All the rocks have undergone considerable contact and dynamic meta-

morphism and the granodiorites deep secular weathering. Epidote, zoisite, and some calcite are universal alteration products.

The rocks are also transitional in part. On account of the faults that separate the various types and that bring contracted types in contact with each other no one continual section could be taken along which a gradual transition could be shown. It would be possible, however, to collect specimens—and this has been done by the writer—which show a gradual, almost perfect transition between the end members. In the central part of the main Saugus anticline—that is, in the lowest part of the granodiorite—there is a distinct basification of the normal granodiorite. The change is gradual, almost imperceptible, until one notices that the granodiorite is almost lacking in potash feldspar, which can be recognized megascopically. The grain and quartz content, however, have varied but little from those of the normal granodiorite. In the Malden-Melrose anticline the rock is a rather basic granodiorite and in places is transitional into a felsic quartz diorite. In general, as stated above, the transition is abrupt and true transitional types are rare. The transition of the granodiorite downward is into quartz diorite; but upward it is into true granite, which contains alkaline feldspar in excess of calci-alkaline feldspar and which occurs, as noted, in contact with the overlying Lynn volcanics, fragments of the granite facies being found also in the basal agglomerates of the volcanics and other subalkaline rocks being absent.

The transition between the quartz diorite and the gabbro-diorite is of less perfect demonstration, partly on account of the poor exposures in North Saugus and Wakefield and also because it is probable that the two types are separated by a fault, which has not been recognized in mapping. To the northwest of Birch Pond the transition is best shown. Immediately north of the Lynn fault at the west end of the pond is gabbro-diorite; north of this quartz enters and the rock passes through a quartz-bearing diorite into a quartz diorite.

STRUCTURAL RELATIONS.

The structural relations of the types are similar. All are intrusive into the old Cambrian or pre-Cambrian sediments, which are now largely confined to roof pendants in the batholith. The Lynn volcanics are younger, resting chiefly on an eroded surface of granodiorite. However, in the Malden-Melrose anticline and south of Castle Hill in Saugus quartz diorite lies immediately below the volcanic rocks. Only the quartz diorite and gabbro-diorite are cut by the Quincy granite; but north of the special area in Newbury all the subalkaline rocks are cut by the binary and alaskitic granites of the Andover type and in Middleton and Topsfield by the Squam granite. Nowhere throughout Essex County, although the different

varieties of the subalkaline rocks are in many places in close contact, is one type distinctly intrusive into any other. The only possible exception is the basic Dedham granodiorite, which as noted above contains inclusions of a much more felsic phase.

The evidence cited appears sufficient to justify a conclusion that all the varieties are parts of one large batholith. It remains to discuss the internal relations of the various phases of this alkaline batholith.

The Lynn volcanics were clearly accumulated upon an old eroded surface of the batholith. (See pp. 31, 34.) With one or two insignificant exceptions this old surface was granodiorite. Commonly, as in the main Saugus anticline, it was composed of the most felsic phase of the granodiorite. In the Parker River basin also the volcanic rocks which occur in a distinct syncline in most places clearly rest upon an eroded surface of granodiorite. (See Pl. I.) The granodiorite has also suffered the most from weathering.

In most places a zone or belt of quartz diorite lies between the granodiorite and the gabbro-diorite. This feature is best shown in the Parker River syncline, in which the granodiorite that forms the center gives way on the flanks to quartz diorite and the quartz diorite in turn to gabbro-diorite. The transitional zone is not well exposed in its entirety, but south of Parker River along the railroad, north of the river along the turnpike, east of the railroad north of Newbury Old Town, and west and north of Topsfield village enough good sections are found to leave no doubt as to the relations.

In the special area the granodiorite occurs south of the Lynn fault and the southern side is certainly the downthrown side. North of the fault is quartz diorite and gabbro-diorite. The fault is most probably a normal block fault (see pp. 110–111) and is not an overthrust nor one of great horizontal displacement. As stated above, there may also be another fault north of this between the quartz diorite of North Saugus and Wakefield and the gabbro-diorite to the north. Again the southern side would be the downthrown.

All this evidence supports most strongly the conclusion that the original subalkaline magma has been differentiated, giving rise to the various phases. The phases have been arranged according to their density the granodiorite on top and the gabbro-diorite below, with a transition zone of quartz diorite. The uppermost part of the granodiorite is the most felsic, and the granodiorite (granite) of Topsfield, which is in contact with the overlying slates and quartzites, is rich in alkaline feldspar. Also the occurrence of inclusions of felsic granite in the granodiorite apparently indicates that the uppermost shell of the batholith now almost completely removed was most felsic. That these inclusions were derived from the upper shell is theoretically highly probable. The upper portion of the batholith would first solidify, but by upward movements in the still molten

magma fragments would be broken off, which as Daly [1] has shown quite convincingly would sink in the molten magma, even though (on account of the great increase of density after crystallization) the present specific gravity of the solidified magma is somewhat higher than that of the sunken fragments.

That the three subalkaline types are arranged according to their respective densities is shown by their specific gravities. The specific gravities given below are the average of careful determinations made by A. C. Metz.[2]

Specific gravity of the subalkaline rocks.

	Number of determinations.	Average specific gravity.
Dedham granodiorite (granite facies of Topsfield)	3	2.663
Dedham granodiorite (normal)	7	2.715
Newburyport quartz diorite	18	2.804
Salem gabbro-diorite	8	2.912

The only objection to the conclusion that the subalkaline rocks are arranged according to their densities is based on the field evidence that blocks of the roof occur in contact with the gabbro-diorite. However, it seems that, except in those few places where the gabbro-diorite actually sends apophyses into the metamorphosed sediments or where other igneous contact phenomena are shown, the structural relations are best explained by faulting. The exceptional blocks of sediments may represent large stoped-off fragments which have sunk in the magma for some distance, as certain large, sheet-like inclusions are known to have done in the quartz diorite of the Newburyport area. Other sediments doubtless represent large roof pendants which hung so deeply into the magma chamber that they projected through the granodiorite and quartz diorite zones. (See fig. 2.)

It is impossible to estimate the thickness of the upper zones, but it is probable that they were not very thick, perhaps not more than 1,000 to 1,500 feet each. The thickness doubtless varied in different parts of the batholith. The character of the country rock seems to have played some part in determining the nature of the igneous rock at the contact; for example, quartz diorite is everywhere in contact with "hornfels." Little attention has been given to the contact assimilation and hybridism between the subalkaline magma and its metamorphosed country rocks, and so no stress will be laid on these phenomena, although they are doubtless of some importance.

[1] Daly, R. A., The mechanics of igneous intrusion (third paper): Am. Jour. Sci., 4th ser., vol. 26, pp. 26–30, 1908.

[2] Metz, A. C., manuscript thesis, Massachusetts Inst. Tech., p. 24, 1911.

The present structural relations and their probable development are shown in figure 2.

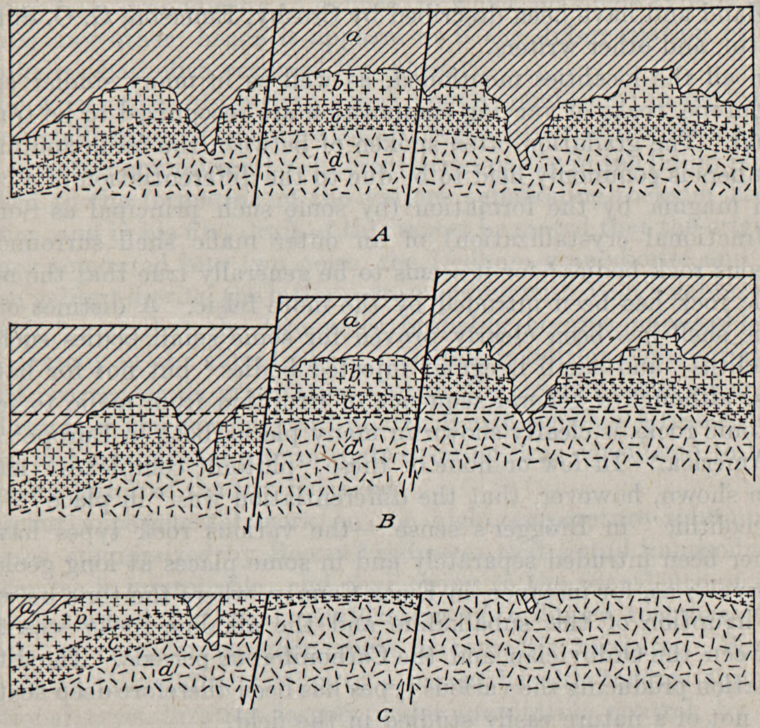

FIGURE 2.—Diagram showing structural relations of subalkaline batholith. *A*, Before faulting; *B*, after faulting; *C*, after faulting and erosion. *a*, Cambrian metamorphic rocks; *b*, Dedham granodiorite; *c*, Newburyport quartz diorite; *d*, Salem gabbro-diorite.

DIFFERENTIATION OF SUBALKALINE MAGMAS.

Batholiths of subalkaline rocks similar to those of Essex County are very numerous throughout the world. In general they occur throughout the "Pacific region" of Harker[1] and also in many places (as in Essex County) in his "Atlantic" provinces. In North America, where, as Harker[2] points out, the distribution of the "Atlantic" and "Pacific" types is most regular, the most extensive occurrence of subalkaline rocks is in the Sierra Nevada and in the Pacific Coast Ranges. The rocks of the Sierra Nevada are best known, having been studied and described by Turner,[3] Lindgren, and many others. Similar rocks in the Coast Range batholith of British Columbia have been described by Dawson[4] and have recently been studied in more

[1] Harker, Alfred, The natural history of igneous rocks, pp. 88–109, 1909.

[2] Idem, p. 99.

[3] Turner, H. W., U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 521–762, 1896. Summarizes existing knowledge, based on many years of field work and several geologic folios.

[4] Dawson, G. M., Report of the Kamloops map sheet: Geol. Survey Canada, vol. 7, pp. 238b–248b, 1894.

detail by members of the Canadian Geological Survey. The "Cortlandt series" of New York, described by Williams,[1] is a classic locality of subalkaline types. Subalkaline batholiths occur throughout New England and have been described by Crosby, Emerson, G. O. Smith, Bastin, and other writers.

In all the localities mentioned, as well as in many similar areas in Europe, rocks of varying composition are recognized to be transitional. The gradation often spoken of between the felsic and mafic members is commonly held to be due to the differentiation of a common magma by the formation (by some such principal as Soret's or fractional crystallization) of an outer mafic shell surrounding igneous rock bodies,[2] for it seems to be generally true that the more mafic rock has been intruded by the more felsic. A distinct outer mafic shell has been clearly proved for some small bodies such as laccoliths [3] and small irregular injected bodies [4] but not for batholiths, although a general sequence of irruption from mafic to felsic plutonic rocks is clearly shown in many places, both in Europe[5] and in America.[6] In few or none of these "plutonic complexes" has it been shown, however, that the differentiation was "in place"—was "laccolithic" in Brögger's sense [7]—the various rock types having rather been intruded separately and in some places at long geologic intervals; as, for instance, in Essex County, where the time between the irruption of the subalkaline and the alkaline rocks was that between the Ordovician and the Carboniferous periods. The differentiation producing the various types has been therefore deep seated[7] and not of a nature easily studied in the field.

Smith, Bastin, and Brown,[8] in mapping in southern Maine a subalkaline batholith similar to that of Essex County, show a mafic periphery, and Loughlin and Hechinger [9] at present hold that the granitic rocks of eastern Massachusetts form one large batholith and are virtually contemporaneous, the mafic types forming a border facies of the batholith. From the evidence already given it has been shown that the most felsic rocks (the alkaline granites and syenites) intrusive into the mafic (the subalkaline rocks) are wholly

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1 Williams, G. H., Am. Jour. Sci., 3d ser., vol. 33, pp. 135-144, 191-199, 1887; vol. 35, pp. 438-448, 1888.

2 Smith, G. O., Bastin, E. S., and Brown, C. W., U. S. Geol. Survey Geol. Atlas, Penobscot Bay folio (No. 149), p. 10, 1907.

3 Weed, W. H., and Pirsson, L. V., Highwood Mountains of Montana: Geol. Soc. America Bull., vol. 6, pp. 389-422, 1895.

4 Harker, Alfred, Carrock Fell: A study in the variation of igneous rock masses: Geol. Soc. London Quart. Jour., vol. 50, pp. 311-336, 1894.

5 Harker, Alfred, The natural history of igneous rocks, pp. 125-131, 1909.

6 Daly, R. A., The Okanogan composite batholith of the Cascade Mountain system: Geol. Soc. America Bull., vol. 17, pp. 329-376, 1906.

7 Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, vol. 1, pp. 178-179, 1894.

8 U. S. Geol. Survey Geol. Atlas, Penobscot Bay folio (No. 149), 1907.

9 Loughlin, G. F., and Hechinger, L. A., An unconformity in the Narragansett Basin of Rhode Island and Massachusetts: Am. Jour. Sci., 4th ser., vol. 38, pp. 55-56, 1914.

distinct from the mafic, are much later, and belong to an entirely separate cycle of igneous activity. On the other hand, it is probable that the subalkaline rocks form a single batholith, consisting of rocks ranging from granodiorite to gabbro, in which no single type is seen cutting any other; hence it appears as if the differentiation of the subalkaline batholith occurred "in place."

The writer formerly believed that Vogt's conclusion[1] in regard to the crystallization of magmas toward rocks either of one mineral or of a eutectic composition by differentiation partly in the liquid phase applied to the formation of the various subalkaline rocks of Essex County, and in his first draft of this report he stated that the original magma separated into two poles, the Dedham granodiorite and the Salem gabbro-diorite, the latter corresponding with Vogt's gabbroidal eutectic;[2] and that the two poles probably became immiscible to some extent in the liquid phase. In this condition differentiation would proceed under gravitative control, the present rocks being the final result. The Newburyport quartz diorite, which is a transitional phase and occupies an intermediate position, was considered to be a mutual solution of the two poles.

Recent experimental work on the high temperature solution of silicates, summarized by Bowen,[3] indicates that liquid immiscibility of silicates is improbable; and that owing to the prevalence of mix crystals formed by the crystallization of ordinary magmas it is useless to consider common rocks as eutectic mixtures. Bowen also shows that differentiation of a parent basaltic magma through fractional crystallization largely under gravitative control, by the sinking of the earlier formed crystals and the squeezing out of the residual liquid, is adequate to produce all the common igneous rocks. A necessary consequence of Bowen's hypothesis is that those batholiths which have differentiated in place and have not been subject to great dynamic movement during crystallization should have a stratified arrangement, the earlier crystallized, heavier mafic minerals collecting near the bottom of the magma chamber to form gabbros, and the later crystallized, lighter felsic minerals collecting near the top of the magma chamber to form granodiorites, granites, or even alkaline rocks. The stage of differentiation recorded by the alkalinity of the last rock to crystallize depends largely upon the rapidity of cooling and that in turn depends largely upon the size of the magma chamber. It appears, therefore, as if the subalkaline batholith of Essex County is almost an ideal example of the differentiation in place of an original basaltic magma through fractional crystalliza-

[1] Vogt, J. H. L., Über Anchi-monomineralische und Anchi-eutecktische Eruptivgestein, Christiania, 1908.

[2] Vogt, J. H. L., Labradorite norite with porphyritic labradorite crystals: Geol. Soc. London Quart. Jour., vol. 64, pp. 81–103, 1919.

[3] Bowen, N. L., The later stages of the evolution of the igneous rocks: Jour. Geology, vol. 23, No. 8, suppl., 1915.

tion under gravitative control. The Salem gabbro-diorite greatly predominated and underlies the Dedham granodiorite, which has in places, near the top of the batholith, a facies that is further differentiated—a biotite calci-alkaline granite; and between the gabbro-

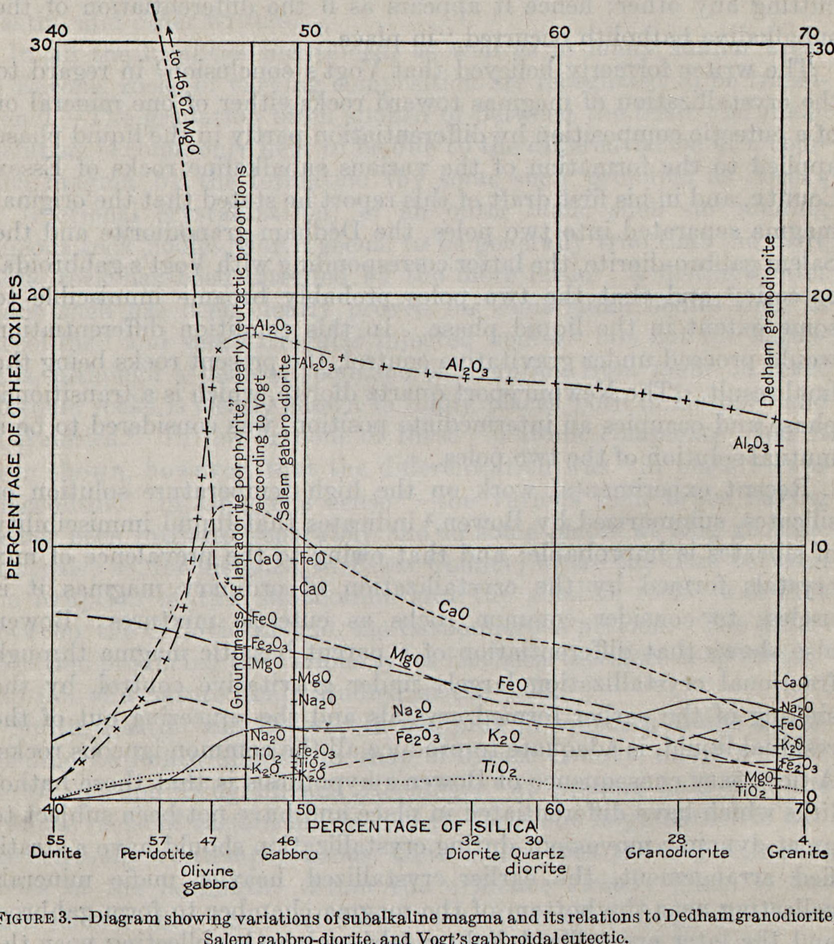

FIGURE 3.—Diagram showing variations of subalkaline magma and its relations to Dedham granodiorite, Salem gabbro-diorite, and Vogt's gabbroidal eutectic.

diorite and granodiorite is the transitional Newburyport quartz diorite.

Whether the alkaline igneous rocks of Essex County represent a further differentiation of the parent magma of the subalkaline rocks is doubtful, although in the light of Bowen's hypothesis there seems to be no theoretic objection. However, if it is a differentiate it is clearly not a differentiate in place, as suggested by Bowen,[1] but a deep-seated differentiate that has been separately intruded from great depths into the completely solidified and much older subalkaline batholith.

[1] Bowen, N. L., op. cit., p. 58.

A noticeable feature of the subalkaline batholith is the uniformity of the predominant Salem gabbro-diorite and its similarity in composition to Vogt's so-called gabbroidal eutectic[1] and also to the average subalkaline magma containing about 48 per cent of silica. The similarity is shown by figure 3, which is obtained by plotting the variation curves of the component oxides of the various subalkaline rocks of average composition as calculated by Daly.[2] This diagram corresponds fairly well with the generalized variation diagram of the "Pacific" branch of igneous rocks compiled by Harker,[3] although the curves are more "linear" than Harker's. The figure clearly shows a zone near the line of 48 per cent of silica, where a marked change occurs in nearly all the curves. Less siliceous rocks tend to be "monomineralische," as for instance the peridotites and dunites, given in the diagram. If hornblendite, pyroxenite, or anorthosite were the "monomineralische" rocks, the curves beyond 48 per cent of silica would of course be radically different from those given, which, however, are probably those of most general application. It appears, therefore, that subalkaline rocks with about 48 per cent of silica are in general similar in their chemical composition and correspond fairly well with the so-called gabbroidal eutectic.

As Bowen has demonstrated, it seems useless to consider rocks as tending toward eutectics, hence the approximate uniform composition of subalkaline rocks near 48 per cent of silica is likely to be due largely to the uniformity of the primary magmas and to the uniformity of conditions under which the magmas crystallized. The principal mineralogic difference between the ordinary subalkaline rocks containing more or less than 48 per cent of silica is the presence of olivine in those containing less and its absence in those containing more. As is well known, olivine is ordinarily the first silicate mineral to separate from a normal basaltic magma, although as Bowen[4] has shown the amount formed depends not only upon the composition of the original magma but upon the rate of cooling and the rate and degree with which the crystallized olivine is removed by sinking. Apparently olivine generally separates out and sinks readily during the early stages of the crystallization of a normal basaltic magma in large plutonic bodies and leaves a fairly uniform magma that finally crystallizes as an olivine-free gabbro, which may or may not be further differentiated. The almost complete absence of olivine in the ordinary subalkaline rock containing about 48 per cent of silica is perhaps due as much to the resorption of remnant crystals of olivine, after olivine had ceased to be stable under lower temperatures, as to

[1] Vogt, J. H. L., Labradorite norite with porphyritic labradorite crystals: Geol. Soc. London Quart. Jour., vol. 64, pp. 81-103, 1919.

[2] Daly, R. A., Average chemical composition of igneous rock types: Am. Acad. Arts and Sci. Proc., vol. 45, pp. 213-240, 1910.

[3] Harker, Alfred, op. cit., pp. 150-151, fig. 44.

[4] Bowen, N. L., op. cit.

the sinking of olivine crystals. It is to this common olivine-free gabbro or gabbro-diorite that the Salem gabbro-diorite corresponds. If olivine ever existed in the subalkaline magma of Essex County, as is suggested by a few remnant traces, either it has been redissolved or it has sunk to a lower zone in the batholith than has yet been exposed.

ALKALINE GROUP.

The rocks of the alkaline group are characterized by high alkalies, especially by high soda, in the less siliceous varieties. The group includes volcanic, batholithic, and dike rocks and the eruption of these three phases follows the normal order stated by Harker [1] and others. (See also p. 108.)

LYNN VOLCANICS.

Lynn volcanics is the term now applied to the so-called felsites, formerly called petrosilex, which occur north of the Boston Basin. They are chiefly effusive rocks but include some closely related dike rocks that apparently served as feeders for the lavas. The effusive types are chiefly felsic, largely quartz keratophyre, but include also trachyte, dacite, and andesite.

DISTRIBUTION.

The Lynn volcanics underlie a broad area extending from Nahant Bay westward across Lynn, Saugus, Melrose, and Malden and continue farther westward into Middlesex County. In Saugus and Melrose the volcanic rocks are separated by a broad anticline which brings the underlying Dedham granodiorite and metamorphosed sediments to the surface. Two smaller anticlines of granodiorite interrupt the volcanics in North Malden. Another small area of the volcanics occurs on Marblehead Neck. Dikes of felsite occur in the Dedham granodiorite of Phillips Point, Marblehead Neck, and Saugus. The volcanic rocks all lie south and east of the Lynn fault. To the south they continue as far as the boundary fault of the Boston Basin. Although none are found immediately north of the Lynn fault another area occurs some 15 miles to the north in the Parker River syncline. This area, however, is mapped by Emerson [2] as Newbury volcanic complex and is regarded by him as older than the typical Lynn volcanics.

QUARTZ KERATOPHYRE.

Normal rock.—The Lynn volcanics are all aphanitic. The prevailing normal or least-altered varieties, here classed as quartz keratophyre, are exposed in numerous road-metal quarries, where they are dark brownish to purplish red. But throughout the area, especially

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[1] Harker, Alfred, op. cit., p. 25.
[2] Emerson, B. K., U. S. Geol. Survey Bull. 597, pl. 10, 1917.

in the western part, the fresh rock is greenish gray and brownish gray. Near the surface and along shear zones the red color has been destroyed, and light greenish gray prevails. The actual surface of the outcrop is commonly white, from a thin coating of kaolin.

The rock is commonly porphyritic. The phenocrysts are of medium size, 2 to 3 millimeters, the range being from microscopic to 4 millimeters, and are not abundant, the rock being usually perpatic. In some varieties, notably from Wakefield and Melrose, the rock is dopatic to sempatic. The phenocrysts are chiefly a white striated feldspar. Quartz is common but usually occurs in very small amount as phenocrysts. Pyrite is also distinguishable megascopically.

On microscopic examination the phenocrysts are seen to be chiefly albite or albite-oligoclase ($Ab_{90}An_{10}$). Few are euhedral, most of them having apparently been broken by the continued flow of the viscous lava after they had crystallized. They are also of rounded outline, as if resorbed by the groundmass. Reentrant bays are, however, almost unknown. Commonly the rounding of the crystal outlines has affected only one or two of the bounding faces (not always the same ones), the remaining faces retaining their original crystal outline.

The other phenocrysts are microperthite and quartz. The former occurs in large irregular grains and is not abundant. Quartz occurs in numerous small rounded grains that are broken and crushed and in places form a mosaic.

The groundmass in large part is microcryptocrystalline. Where coarsely crystalline enough to be determinable it is seen to consist largely of albite, quartz, and probably some potash feldspar. Scattered through the groundmass are small green biotites and very small grains of zircon and apatite. The microcryptocrystalline texture is probably due to the devitrification of an original glass. Washington notes the occurrence of glass [1] in these rocks, but the writer could find none in some 30 specimens examined by him. However, the conclusion that the texture was originally glassy is supported by the occurrence of spherulites, chiefly of albite, in some of the more coarsely crystalline varieties. These spherulites, although occurring throughout the groundmass, are more abundant near the albite phenocrysts.

Alteration.—The rock is not badly altered, although the feldspars are clouded with sericite. (In the more altered part of the formation some of the feldspars are almost completely sericitized.) The biotite has altered to chlorite and magnetite. Where magnetite occurs in considerable quantity it has darkened the rock and has also probably furnished the iron of the limonite or earthy red oxide that occurs in clouds throughout the groundmass. Small grains of epidote and

[1] Jour. Geology, vol. 7, p. 291, 1899.

calcite also occur, perhaps derived in part from original hornblende, which occurs in some varieties.

Chemistry and classification.—The chemical nature of the rock is shown in the following analyses:

Analyses of Lynn volcanic rocks and average composition of quartz keratophyre.

	1	2	3
SiO_2	69.64	70.64	75.45
Al_2O_3	13.04	15.34	13.11
Fe_2O_3	4.15	1.83	1.14
FeO	1.98	1.10	.66
MgO	.32	.52	.34
CaO	.54	1.24	.83
Na_2O	5.46	5.23	5.88
K_2O	3.55	3.55	1.26
H_2O+	.69	.38	.69
H_2O-	....	.14	....
TiO_2	.55	.90	.17
MnO	....	Trace.	.29
	99.92	100.87	99.83
Specific gravity	....	2.632	....

1. Quartz keratophyre, quarry at West Lynn, Mass. S. J. Schofield, analyst. Fe_2O_3 probably too high and Al_2O_3 too low. Washington, H. S., U. S. Geol. Survey Prof. Paper 99, pp. 150–151, 1917.
2. Rhyolite, Marblehead Neck, Mass. H. S. Washington, analyst. Washington, H. S., Jour. Geology, vol. 7, p. 292, 1899.
3. Average composition of quartz keratophyre. Daly, R. A., Average chemical composition of igneous rock types: Am. Acad. Arts and Sci. Proc., vol. 45, p. 220, 1910.

Norms of Lynn volcanic rocks.

1[a]				2[b]			
Q	23.10	Di	1.73	Q	23.28	Hy	1.30
Or	21.13	Mt	4.87	Or	21.13	Mt	.70
Ab	46.11	Il	1.06	Ab	44.02	Il	.67
An	.56	Hm	.76	An	6.12	Hm	1.28
				C	.61		
Class I'', order 4, rang 1, subrang 4. Femic, kallerudose.				Class I, order 4, rang (1) 2, subrang ''4. Kallerudose-lassenose.			

[a] Washington, H. S., U. S. Geol. Survey Prof. Paper 99, p. 151, 1917.
[b] Idem, p. 219.

The normal volcanic rock is clearly related to the alkaline granites (see p. 71), especially to the quartz-poor phase of the Quincy granite. It is therefore the effusive equivalent of an alkaline granite and is best classed according to Rosenbusch [1] as a quartz keratophyre. The Lynn volcanics differ in chemical composition from normal rhyolites in their low content of CaO and in the predominance of Na_2O over K_2O. Both of these features are characteristic of quartz keratophyres in general. Both rocks are lower in silica than the average quartz keratophyre, owing to the trachytic tendency of the Lynn volcanics. However, this tendency is not sufficient to create a new rock type, and the Lynn volcanics are therefore classed as trachytic quartz keratophyres.

[1] Rosenbusch, H., Elemente der Gesteinslehre, p. 267, 1901.

TRACHYTE.

Slight trachytic variations of the prevailing Lynn volcanics are common in the area but do not occur in large amount. In south Saugus and Melrose a greenish-gray variety has the normal crypto-crystalline groundmass but has more and larger phenocrysts (sempatic), not only of feldspar but also of hornblende. The feldspars have been sericitized but are probably albite. In view of the altered characteɪ of the rest of the rock, the hornblende is remarkably fresh. It occurs in yellowish-green rectangular crystals 2 to 4 millimeters in length and has the optical properties of common hornblende. The groundmass is considerably altered but appears to have consisted chiefly of albite, orthoclase, hornblende, and possibly quartz and biotite, with accessory magnetite. At present the feldspathic minerals have been partly sericitized, and chlorite, which from its appearance may have been derived in part from original biotite, occurs in small scattered flakes throughout the groundmass. Epidote occurs in disseminated grains and in veinlets with quartz. This phase of the volcanic rocks is more nearly a normal trachyte.

DACITE.

The more basic varieties of the Lynn volcanic rocks, here classed as dacite, occur as dikes and irregular interbedded flows and also as fragments in the agglomerate of Vinegar Hill. Some of the dark fragments are dark olive-gray, with small white porphyritic feldspars; the groundmass is in excess (perpatic). The largest phenocrysts are 4 or 5 millimeters in length. A few quartz phenocrysts are distinguishable megascopically.

Under the microscope the phenocrysts are seen to be oligoclase ($Ab_{75}An_{25}$) and quartz. Both have been resorbed, the quartz being not only rounded but deeply embayed. The groundmass consists essentially of oligoclase (probably about $Ab_{70}An_{30}$) and hornblende. The feldspar occurs in laths with interstitial secondary minerals, chiefly chlorite. Magnetite and possibly quartz are accessory. The alteration has been moderate, although the hornblende has almost entirely gone over to chlorite. The other secondary minerals are sericite and epidote. The rock, which is classed as a dacite, is petrographically quite distinct from the trachytic rocks, although it is certainly a member of the volcanic formation.

ANDESITE.

Andesites also occur in the Lynn volcanics, especially in the Melrose area. They are dense greenish to purplish-green rocks, and are usually amygdaloidal, the amygdules being composed of epidote and quartz. They originally consisted of andesine, feldspar, and

hornblende with accessory magnetite but are now greatly altered to sericite, saussurite, and chlorite.

TEXTURAL VARIETIES.

Besides the normal glassy or porphyritic varieties of the Lynn volcanics there are a great number of volcanic rocks which, although they may be of the same composition as the quartz keratophyre, have marked structural or textural differences. These rocks may be subdivided into those of perlitic or spherulitic texture, those of taxitic texture, and the pyroclastics.

Perlitic and spherulitic varieties.—Traces of original spherulitic textures are found on the volcanic rocks of the area but are not common. Spherulitic texture is rarely distinguishable megascopically but is observed occasionally on microscopic examination. Small rounded masses of slightly different texture, many of which have concentric structure, occur in the normal lavas of the Parker River basin in Newbury and weather out on the surface. The rock from which they come resembles a conglomerate with a peculiar botryoidal appearance and has been called locally "toad stone." The masses have been devitrified and may be the spheroids of an old perlite. They can not be definitely distinguished from old spherulites but suggest most strongly old lithophysae. No such well-developed "lithophysae" occur in the special area, but on the top of Mount Hood in southeast Melrose traces of such a texture are found.

Taxitic varieties.—The term "taxitic" is used to designate those structures which have apparently been formed by the flowing of a very viscous or partly solidified or other heterogeneous lava. Loewinson-Lessing [1] has defined the term as designating those irregular structures in lava that resemble an apparent clastic texture and that give the rock a heterogeneous blotched appearance. The structure has been formed, according to Loewinson-Lessing, by the differentiation—that is, "liquation"—into contrasted mineralogic and textural portions, the separated portions being variously affected by the subsequent movement of the lava. He subdivides the general texture into three special types, ataxitic, irregularly mottled or brecciated; eutaxitic, banded or with flow lines; and spherutaxitic, containing porphyritic crystals. It is impossible to tell these structures from those produced by other processes than "liquation." It seems advisable, therefore, to extend the definition of the general term taxitic to structures produced by the movement of any heterogeneous lava which is viscous or partly solidified.

Flow structure is well developed in many places, notably on Marblehead Neck and in west Melrose. On a weathered or polished sur-

[1] Loewinson-Lessing, F., Zur Bildungsweise und Classification der Klastischen Gestein, pp. 228–235, 1888.

face the flow lines are well shown megascopically by alternating colors due in part to a difference of grain, which causes the iron oxide to stain contiguous bands to slightly different tones of brownish red. Some white sericitized bands occur, and many of them include phenocrysts or small inclusions of a denser lava. The flow lines bend around these phenocrysts or small inclusions and, being further greatly contorted in most places, rarely give a definite clue to the true attitude of the volcanic rocks. The flow lines are commonly faulted, probably by the movement of the viscous lava, which brecciated the solidified portions.

Another type of taxitic texture, ataxitic, consists of a great number of small angular fragments of a very dense lava in a matrix of essentially the same composition. The fragmental nature is often plainly distinguishable in the hand specimen on account of the slight difference in color of the fragments and matrix. Most of the inclusions are darker than the matrix and were originally more glassy and are still microaphanitic. In some rocks, however, the fragments are more coarsely crystalline than the matrix, and some of the fragments are even porphyritic. These ataxitic varieties may be in part flow breccias, as defined by Iddings.[1] However, on account of their homogeneity of material they appear to have been formed largely by the fracturing and brecciation of a crust on a viscous flowing lava.

AGGLOMERATES AND BRECCIA.

General character.—Tuffs, breccias, and agglomerates, clearly of explosive origin, are abundant in the Lynn volcanics and are distinguished chiefly by the heterogeneous character of the included fragments. As this is their only marked distinction, and as there are no water-laid or stratified tuffs in the area (though some occur in the southern part of the Boston Basin) it is virtually impossible to distinguish the fine tuffs from the flow rocks. The fragments of the coarse rocks are derived from both the volcanics and the underlying crystallines, the Dedham granodiorite and Cambrian or pre-Cambrian quartzites, slaty quartzites, and hornfels. They range in size from a few millimeters to large rounded or subangular fragments 3 to 4 meters in diameter. The smaller ones are usually angular. The fragments are very numerous and are generally packed closely together. The matrix is usually light greenish and is composed of very fine volcanic material, chiefly feldspathic, with quartz and secondary minerals such as chlorite and epidote.

Breccias.—In places the rock is largely composed of volcanic material, as in many of the breccias of the eastern part of Lynn Woods. These consist not only of fragments of porphyritic lava and taxitic

[1] Iddings, J. P., Igneous rocks, p. 331, 1909.

varieties but also of fragments of single crystals of albite and quartz. The larger fragments occur in a very fine fragmental groundmass. These breccias are almost certainly of true explosive origin—that is, they are coarse tuffs unstratified by water.

Agglomerates of Vinegar Hill.—In other places, notably at Vinegar Hill in Saugus, the breccia is very coarse and heterogeneous. Larger fragments of Dedham granodiorite and different varieties of volcanic rocks occur close together in the most irregular fashion. The granodiorite fragments are usually the more rounded. They are more weathered and contain a larger percentage of red-weathering feldspar (microperthite and microcline) than most of the Dedham granodiorite exposed in place to-day. Fragments as large as 4 meters in diameter occur, and small fragments are abundant. The granodiorite has also been broken into its constituent minerals, and fragments of the feldspar and quartz occur embedded in the volcanic matrix. The amount of granitic material is so large that in places the resulting rock resembles a crushed granite.

The volcanic rocks in the agglomerate range from light-colored, dense, siliceous-appearing rocks, either porphyritic or taxitic, through normal reddish porphyries and flow breccias, to dark dacites and siliceous andesites.

Away from the centers of very coarse agglomerates the fragments are smaller. It is therefore probable that some agglomerates were formed during eruption in or near the vent of one of the old volcanoes. The typical agglomerate of Vinegar Hill was almost certainly thus formed.

Basal agglomerates.—Where the volcanic rocks are seen to overlie the Dedham granodiorite directly, their base is marked by a basal agglomerate similar to that observed by Iddings[1] at Sepulchre Mountain, where the lower breccia contains fragments of the underlying crystallines. This agglomerate is similar in appearance to the agglomerate of Vinegar Hill but does not contain such a variety of fragments or such large ones. The groundmass is finer grained and may not always be truly fragmental.

A peculiar phase of the basal agglomerate is well exposed in a quarry near the railroad, 500 yards southwest of Saugus railroad station. This quarry has been called by local geologists the "ball" quarry on account of its round masses of granodiorite.

The "ball" quarry agglomerate is made up almost entirely of granitic material. Large subangular to rounded and small subangular fragments of a felsic phase of the Dedham granodiorite occur in a fine-grained sericitic and chloritic matrix with angular fragments of quartz and feldspar. (See Pl. III.) Agglomerate of this type grades downward into greatly altered granodiorite and upward

[1] Iddings, J. P., U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 634, 1891.

POLISHED SURFACE OF "BALL" QUARRY AGGLOMERATE.

into a normal breccia largely composed of volcanic material. The agglomerate contains also rounded fragments of an old diabase dike which originally cut the granodiorite. The diabase fragments show concentric weathering or possibly merely discoloration.

Under the microscope the minerals are seen to be those of the felsic phases of the Dedham granodiorite (quartz, microperthite, and oligoclase), although microperthite is more abundant than in any of the granodiorite seen in place within the special area. Rock grains and fragments of crystals are present, and both are clearly derived from the granodiorite. The minerals have been characteristically metamorphosed and altered. No original mafic minerals occur, although magnetite is common. The groundmass consists largely of sericite, flakes of chlorite, and grains of epidote and calcite. Veinlets of epidote, quartz, and calcite are common.

The overlying volcanic breccia contains fragments of quartz and feldspar crystals which show the effect of intense strain and alteration and were doubtless derived from the underlying granodiorite. Epidote is more abundant in the groundmass than in the coarse agglomerate.

The agglomerate may be entirely of explosive origin or, on the other hand, may represent an old talus of decomposed granodiorite indurated by the heat and pressure of the lava which flowed over it. A conclusion intermediate between the two extremes is most likely—that is, that the agglomerate represents an old decomposed granodiorite through which the volcanics were erupted. Considerable volcanic material was added to the granitic detritus in places, but in other places the detritus was chiefly solidified by heat and pressure and by emanations from the molten lava. That the granodiorite had already been broken down by the weather is strongly suggested by the large rounded fragments and by the apparent ease with which it has been separated into its component crystals. The more and more oxidized concentric bands in the rounded inclusions of diabase have probably been formed not by the alteration of fragments of fresh rock in the agglomerate but by the weathering of the old diabase dike before the eruption of the volcanics. Dikes of a volcanic breccia, assuredly of volcanic and explosive origin, which break through the agglomerate, prove that volcanic material was exploded through the granodiorite. The thickness of the agglomerate is considerable, about 150 to 200 feet, supporting the conclusion that the volcanics were erupted through a decomposed rock.

Breccia dikes.—The so-called breccia dikes are light greenish-gray fine-grained rocks, the large easternmost dike at the "ball" quarry being almost cherty in its appearance. Their fragmental nature is clearly shown microscopically, although it is possible that the very

fine grained cherty variety is a devitrified glass with numerous angular fragments of country rock ranging from 0.01 to 1 millimeter in diameter, the average being about 0.1 millimeter. They are chiefly quartz, perthite, and albite, packed together closely but irregularly. The matrix, which was apparently chiefly feldspar (albite and orthoclase?) and quartz, with some accessory or secondary pyrite, has been sericitized and contains some epidote and chlorite.

Similar dikes occur in the granodiorite of the Maplewood anticline. The fragments are, however, larger and include not only particles of the country rock but also of quartz and albite of volcanic origin. The volcanic quartz and albite are much less altered and strained than the same minerals derived from the granodiorite. The groundmass is also finer grained and more uniform, virtually cryptocrystalline. If the rock has not been actually molten, the temperature has been high enough to sinter the fragments of the groundmass together. The dikes in the granodiorite have almost certainly been molten in part, but the coarser dikes in the agglomerate have not necessarily been so.

DIKE ROCKS.

General character.—Dikes of volcanic material are fairly abundant, cutting not only the volcanic rocks themselves but also the underlying Dedham granodiorite. They are more abundant in the volcanics, cutting the agglomerate and breccia, notably at Castle Rock on Marblehead Neck and south of High Rock in Melrose. In the flow rocks the dikes are smaller and irregular. In the granodiorite they are larger and for the most part more regular, though many of them end abruptly and vary greatly in width and strike. They occur throughout the Dedham granodiorite on Marblehead Neck, on Phillips Point, in the Saugus area, and in the Maplewood anticline.

The volcanic dikes range from normal porphyritic quartz keratophyres, indistinguishable from the effusive types, to dark basic-looking andesites, those of the more felsic variety being the more abundant. Although their mineral composition is identical with that of the effusive varieties the texture of the groundmass of many of them is trachytic. The microlites of albite-oligoclase also have a slight tendency to radial arrangement.

The keratophyre dikes in the granodiorite of Phillips Point are greatly altered. In the same dike the rock varies from light gray to dark green or red, the dark colors being found near the borders of the dikes. Red and green are found in the same dike. The contact between the two types, strongly contrasted in color, is sharp and very irregular. The original rock seems to have been similar to the normal porphyritic varieties with a trachytic groundmass and

phenocrysts of albite and possibly of quartz. The grain of the groundmass is finer in the dark portions near the border. The border facies are also richer in mafic minerals (magnetite and presumably hornblende).

The groundmass has altered to sericite with a great deal of secondary quartz. Even in the center of the dike the feldspar phenocrysts are largely replaced by calcite, and near the contacts they are entirely replaced. Chlorite and limonite are abundant, the predominance of the one over the other giving the rock its characteristic color. The large amount of calcite suggests that the lime was derived in part from the country rock.

Certain spherulitic quartz porphyry dikes that cut the Salem gabbro-diorite and Quincy granite resemble the volcanics in appearance. They are classed with the volcanic rocks by Washington,[1] but structurally they are entirely distinct and form one of the dike phases of the alkaline plutonic rocks. No effusive types so rich in quartz are known.

Bostonite or keratophyre.—On the west side of Marblehead Neck, associated with volcanic rocks, the well-known type occurrence of bostonite is exposed.[2] The rock at this place has been very fully described petrographically by Rosenbusch, Sears,[3] and Washington[4] and need not be redescribed here. The following analyses have been published:

Analyses of bostonite or keratophyre from Bodens Point, Marblehead Neck.

	1	2
SiO_2	71.40	70.23
Al_2O_3	14.76	15.00
Fe_2O_3	1.68	1.99
FeO	.72	(*a*)
MgO	.55	.38
CaO	.10	.33
Na_2O	4.79	4.98
K_2O	5.16	4.99
H_2O+	1.46	1.28
H_2O-	....	.91
TiO_2	....	.03
P_2O_5	....	.06
MnO	Trace.	.24
	100.62	100.42

a Not determined.

1. H. S. Washington, analyst. Jour. Geology, vol. 7, p. 293, 1899.
2. T. M. Chatard, analyst. Sears, J. H., Harvard Coll. Mus. Comp. Zool. Bull., vol. 16, p. 170, 1890.

Sears and Washington describe the rock at this place as effusive and therefore classify it as a keratophyre rather than as a bostonite.

[1] Jour. Geology, vol. 7, p. 291, 1899.
[2] Rosenbusch, H., Min. pet. Mitt., vol. 9, p. 447, 1890.
[3] Sears, J. H., Harvard Coll. Mus. Comp. Zool. Bull., vol. 16, p. 167, 1890.
[4] Washington, H. S., Jour. Geology, vol. 7, p. 292, 1899.

Wadsworth [1] also believes that the rock is a flow rock overlying the normal effusive types and agglomerates ("conglomerates"). From the field occurrence it is impossible to reach any assured conclusion, for the rock is exposed only at low tide and is separated from other volcanic types by an eroded joint plane. Chemical analyses, however, show that it is closely related to the known effusive types of the Lynn volcanics, the only marked difference being in the amount of potash, which is greater in the bostonite, from the occurrence of anorthoclase as the chief feldspar instead of albite. Whether the rock occurs as a flow or as a dike is largely a matter of personal opinion, but there appear to be two reasons for believing it to be a dike rather than a flow. Although if a flow it would apparently overlie the volcanic rocks as exposed at that portion of Marblehead Neck, it would nevertheless be in the lower part of the volcanic formation, for the volcanics of Marblehead Neck rest directly upon the Dedham granodiorite and are not of any great thickness. If it were a flow in the lower or middle part of the volcanic formation, it would probably, like other flows, have considerable lateral extent and would be found in other parts of the volcanic area where the lower and middle members of the volcanic formation are well exposed. But no such occurrence is known. Dike rocks, on the other hand, may have, of course, a very small and local occurrence. Again, the trachytic texture of the groundmass is characteristic not of the flow rocks of the volcanic formation but of the dike rocks. For these reasons the writer prefers to consider the disputed rock as a dike, although most intimately associated with the effusive volcanic rocks and therefore a true bostonite.

METAMORPHISM.

Jointing.—The Lynn volcanics have been subjected to great dynamic forces. Instead of yielding by flexure, the glassy rocks have yielded by almost minute fracturing and more rarely by shearing. The intense fracturing into small rhombohedral blocks, few of them very regular, is well brought out on the weathered surfaces. The surfaces of the ledges are jagged and angular, in marked contrast to the smooth, rounded ledges of the plutonic rocks. The jointing is irregular, and no definite results have been obtained from the compilation of the strikes of the joints.

Silicification.—In small areas volcanic rocks of even the dense porphyritic varieties are silicified. Silicification is pronounced near the Lynn fault, especially so along the neighboring small granitic intrusions. Some of the breccias, where cut by the felsitic dikes, are silicified, notably at Castle Rock on Marblehead Neck.

[1] Wadsworth, M. E., Boston Soc. Nat. Hist. Proc., vol. 21, p. 288, 1881.

The silicified rocks are gray and more rarely greenish gray. Megascopically they are apparently very siliceous; but under the microscope the change, except in a few places, is not marked. Veinlets of quartz and of quartz and epidote cut the rock, which is usually greatly fractured and in many places sheared. Parts of the groundmass have been recrystallized into very small rounded grains of quartz and clear unstriated feldspar, which average 0.01 millimeter in diameter. In the fragmental volcanics secondary quartz occurs around the original quartz fragments.

Cherts.—Where the silicification of the fine-grained tuffs or possibly devitrified obsidians is more extreme the rock has the appearance of a cherty quartzite. A similar rock (p. 65) cuts the "ball" quarry agglomerate. The "cherty" rocks usually retain some traces of their original texture in their irregular grain, which gives them a patchy, blotched appearance. Under the microscope feldspar is seen to be more abundant than in a quartzite, and hornblende occurs in places. Quartz occurs not only in veinlets but in irregular clusters. The rock also weathers white, having a thin coating of fine silica and kaolin. Although in many places the volcanic origin of the rock is unquestioned these cherty rocks pass into varieties whose origin would be very obscure except for the field relations. Quartz occurs in these more metamorphosed types in large quantity as relatively large, irregular mosaics of broken grains in a finer-grained sericitic and chloritic groundmass. Little feldspar is recognizable. Near the area of intrusive granite south of Wenuchus Lake, in Lynn, the original texture is unrecognizable in the thin sections, although megascopically, especially on the weathered and glacially polished surface, an original porphyritic or eutaxitic texture is in many places strongly suggested. The grain of the extremely altered types is coarser, about 0.1 millimeter. Although composed chiefly of quartz, the rocks contain irregular finer-grained patches of obscure mineral composition.

Similar felsitic rocks occur in the contact-breccia zone of the Quincy granite in the Peabody stock. It has been impossible to distinguish them clearly from very fine grained quartzites or silicified slates. As they contain over 80 per cent of silica (88 per cent in one specimen) it seems best to consider them sedimentary rocks.

The "cherty" rocks which occur as dikes, as at the "ball" quarry and Castle Rock, Marblehead Neck, are probably devitrified glasses, the component minerals being essentially feldspar and quartz of almost submicroscopic grain.

STRUCTURAL RELATIONS OF LYNN VOLCANICS.

The Lynn volcanics clearly rest upon an eroded surface of the subalkaline batholith, chiefly upon the Dedham granodiorite. That they were erupted through and accumulated upon a weathered surface of

granodiorite has been clearly shown. Nowhere do the volcanics rest unconformably upon alkaline granite of the Quincy type. Instead, two small intrusions of Quincy granite along the Lynn fault have apparently silicified and altered the neighboring volcanic rocks, and one of them, south of Lake Wenuchus in North Lynn, is actually seen to cut the altered rocks, which can be traced into comparatively unaltered and undoubted volcanic rocks. Metz[1] states that the volcanic rocks of the Parker River syncline are cut by apophyses of the Andover granite. The basal member of the volcanic formation, wherever exposed, is a basal agglomerate, which grades upward into finer tuffs, and these in places are overlain by flows of normal porphyritic quartz keratophyre. The basic members occur in the upper portion of the formation. Some interbedded andesitic flows are known, but the basic volcanic rocks occur chiefly as irregular dikes in the felsic rocks. The basic flows of the Parker River basin are more numerous and occur in the central part of the syncline—that is, in the highest part of the formation.

The present attitude and thickness of the Lynn volcanics can not be accurately determined. The flow lines have been so badly contorted by the flowing of the viscous lava that they give few indications of the attitude of the original bedding. The contacts of the different members of the formation are irregular and rarely show a distinct bedding. In most places where the bedding is apparently determinable it is very steep, except on Marblehead Neck, where as a rule the dips do not exceed 40°. The strikes are generally in the northeast quadrant, and the dips are steep to the northwest. On Marblehead Neck the strikes are chiefly west of north and the dips range from gentle to steep to the west and east. At Castle Rock the strike ranges from N. 30° W. to N. 50° E.

The Lynn volcanic rocks have been warped as a whole (see Pl. II) into a broad anticline that strikes about N. 40° E., in the central part of which, in Saugus and Melrose, the unconformably underlying granitic rocks are exposed. The northern limb of the anticline has been extensively faulted. In North Malden there are two smaller anticlines with approximately parallel strikes (N. 35°–40° W.) called the Malden-Melrose and Maplewood anticlines, which suggest that the volcanic rocks have been warped into broad folds. In detail the rocks have in many places been tilted on end, as shown by the recorded dips. They have also been faulted extensively, although the faults with one or two exceptions are of no great displacement.

The thickness of the formation is probably not great, as is suggested by the number of places at which breccias and agglomerates apparently related to the basal agglomerate occur throughout the areas.

[1] Metz, A. C., manuscript thesis, Massachusetts Inst. Tech., p. 22, 1911.

If the limbs of the larger folds dip 20°, which is probably a maximum, and if the greatest exposed width on the southern limb of the large anticline in Saugus is roughly 7,000 feet, the calculated thickness would be 2,400 feet. It is probable, therefore, that 2,000 feet is a moderate estimate of the thickness.

PLUTONIC ROCKS.

The alkaline plutonic rock bodies occur as batholiths, stocks, and minor apophysal phases. They range from nephelite syenites through alkaline syenites to alkaline granites. The main bulk of the batholiths and stocks is granite, the syenites being marginal differentiates. The granites are therefore described first, although they doubtless crystallized somewhat later than most of the syenites.

QUINCY GRANITE.

NAME.

Quincy granite is a general name which includes all the granites of alkaline type in the special area except the Andover granite. To the northeast the granite of Beverly and Manchester extends to Cape Ann, where, as is well known, it is extensively quarried. The granite of Cape Ann, although very similar to the granite of the Peabody stock and in places even identical with it, varies more in mineral composition and texture. For instance, the well-known granite quarried at Rockport is much more siliceous than the granite of the Peabody stock. As the varieties of the granite of the Cape Ann area have not been carefully studied and mapped in detail, it seems best at present to include those having characteristics similar to the granite of the Peabody stock with the Quincy granite. However, there is some difference between the typical granite of the Peabody stock and those of Beverly and Manchester.' Another distinctive variation of the normal type occurs in East Danvers.

DISTRIBUTION.

The Quincy granite occupies a large area in the town of Peabody, where it forms a roughly circular stock or small batholith measuring $3\frac{1}{2}$ by $5\frac{1}{2}$ miles. To the northeast it underlies the greater part of the towns of Beverly and Manchester and forms part of the large Cape Ann batholith. An elongate stock $1\frac{1}{2}$ miles long by somewhat more than one-half mile wide occurs in Marblehead and Swampscott. In North Lynn and Swampscott a string of small intrusive masses, most of them too small to map, connects the small Marblehead stock with the southeastern part of the Peabody stock. One mass in North Lynn is over a mile long but less than one-quarter of a mile wide.

LITHOLOGIC CHARACTER.

Composition.—The Quincy granite is a coarse and fairly uniform grained rock. Its chief constituent is a rectangular alkaline feldspar with prominent cleavage faces, commonly showing Carlsbad twins. Quartz occurs in smaller colorless grains in the interstices of the feldspar crystals. The colored minerals make up a small percentage of the rock. They are euhedral, although they have a less regular outline than the feldspar. The pronounced regularity of the feldspar gives the rock its characteristic subporphyritic appearance.

Color.—The Quincy granite is gray on the freshly broken surface but when exposed to the air changes in a few hours to a dull grayish green. This change is similar to that described by Daly [1] as affecting the nordmarkite of Mount Ascutney but is not so pronounced. The change apparently affects nearly all of the very fresh granite of the area. Some exceptions are found, however, notably in the small Marblehead stock, where the rock is finer grained and more like the "Rockport gray" granite of the trade. This variety is light gray and does not change on exposure.

The Quincy granite, where slightly weathered near the surface, and where more fractured than common, is lighter colored and does not change color. Where greatly fractured and sheared it has weathered to a deep reddish brown. The red granite is virtually confined to Beverly and Manchester. Ordinary surface weathering has broken down the granite in a few places into a coarse brownish-yellow granular laterite of quartz and feldspar.

The color of the granite as a whole is controlled by that of the feldspar. In the normal rock the feldspar turns greenish on exposure. Under the microscope the feldspar is seen to be traversed by very thin veinlets of a green chloritic mica in bands less than 0.03 millimeter thick, and it seems most probable that a slight oxidation of this chlorite causes the deepening and intensifying of the green. Daly, after careful experimentation, came to the conclusion that the change in color in the nordmarkite of Mount Ascutney was due to oxidation and not to carbonization. He states [2] that the oxidation affects minute granules of ferrous oxide and changes them to ferric oxide—that is, to a yellow color. The combination of the yellow with the original blue gray of the under layers affords the green. It is doubtful if the blue is strong enough to compensate a distinctly yellowish tone enough to give the appearance of a deep green. The feldspar of the nordmarkite of Mount Ascutney likewise shows bands of green chloritic matter that are, in fact, wider and more numerous than those in the Quincy granite. Slight oxidation of such a mineral

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[1] Daly, R. A., The geology of Ascutney Mountain, Vt.: U. S. Geol. Survey Bull. 209, pp. 51-53, 1903.
[2] Idem, p. 52.

as chlorite might well change its color to a darker green and thus affect the color of the entire rock. Chloritic bands in the feldspar are virtually absent from the gray granite of Rockport. In the light-gray, slightly weathered varieties of the Quincy granite the feldspar has been kaolinized, and the white of the kaolin has obscured and overcome the green of the chlorite.

Mineral association.—The mineral association and texture is uniform throughout the granite, but the proportion of the various minerals shows very considerable variation. Under the microscope the essential minerals are seen to be microperthite, quartz, albite, and katophorite, and the accessory minerals hedenbergite (which is essential in some varieties), a colorless pyroxene of unknown variety, basaltic hornblende, biotite, magnetite and ilmenite, zircon, apatite, and probably allanite. A great number of rare minerals have been described from the granite at Cape Ann, many of which doubtless occur also in the granite of the Peabody stock.

The early secondary minerals, perhaps formed in part under magmatic conditions, are glaucophane, brown biotite, and magnetite. There is also a peculiar yellow mineral, in some specimens isotropic, which has been formed by the alteration of the hedenbergite and which is apparently a hydrous iron oxide, perhaps mixed with oxides of some of the rare earths, such as zirconium or cerium, that are known to be present. The later secondary minerals, chiefly chlorite and kaolin, are present in very small amount, except locally where the rock is weathered.

Texture.—The texture of the granite is subhedral. The microperthite, which is euhedral, forms the largest grains, which are 8 to 10 millimeters in length. The average diameter of the microperthite, based on the diameter of virtually all the grains in several thin sections, is only 2.1 millimeters. In this determination undue weight is given to the small grains, by far the larger amount of microperthite occurring in grains over 5 millimeters in diameter. Smaller euhedral crystals of albite and mafic minerals occur. Quartz and albite are interstitial and have crystallized in small grains with irregular contacts, many of which include each other so as to form a micrographic texture. The average diameter of the quartz is 1.4 millimeters, although again the larger amount of quartz occurs in larger grains.

Microperthite.—The microperthite is an intergrowth of soda orthoclase and albite, although in a few places microcline (presumably soda microcline) is intergrown with the albite. The microperthite is the most abundant mineral, forming from 50 to 70 per cent by volume of the rock, although in some of the contact facies of the Peabody stock it is as low as 35 per cent.

The two minerals of the intergrowth, which is remarkably regular, are sharply defined. They are easily distinguished by the polysynthetic twinning of the albite, its higher birefringence, and its slightly higher relief. On the 010 face the extinction of the albite is 19° and that of the soda orthoclase 11°. In slightly weathered samples the two minerals are easily distinguished, as the soda orthoclase alters to kaolin much more readily than the albite.

The potash and soda feldspar are present in the microperthite in about equal amounts. The calculated average percentage by volume is 52 per cent orthoclase to 48 per cent albite—that is, 51 parts by weight of orthoclase to 49 parts of albite. In different rock specimens and crystals the respective components vary considerably, the extreme limits noted being 37 and 68 per cent of orthoclase. The rock with the high percentage of orthoclase occurs near the contact with gabbro-diorite near Montrose railroad station.

The average proportion corresponds very well with the eutectic point given by Vogt for orthoclase and albite.[1] The eutectic point that he deduces is about 42 parts of pure orthoclase to 58 parts of pure albite. However, more albite enters into solid solution with orthoclase than orthoclase enters into solid solution with albite; therefore, in the resulting eutectic, the percentage of soda orthoclase to potash albite is higher than that of pure orthoclase to pure albite. From the data given by Vogt it would appear that there are about equal parts of the two "impure" minerals (mix crystals) in the resulting eutectic.

That such eutectic as Vogt suggests actually exists has not as yet been proved by actual experiment, owing to the failure to prepare the alkali feldspars by simple dry fusion. However, since this report was written Dittler[2] has experimented with the alkali feldspars, concluding that they form a continuous series of mix crystals the freezing curve of which passes through a minimum; and Warren,[3] from a study of the microperthites in the Quincy granite of the Quincy area similar to those in the Peabody stock, has concluded that the potash and soda feldspars form a continuous series of mix crystals under certain conditions, but under other conditions, probably under somewhat lower temperatures, are only partly miscible in the solid state and hence form a eutectic. He further concludes that the crystals of microperthite are the result of a sluggish and hence as a rule incomplete unmixing (below the transition point) of earlier-formed mix crystals so that they represent only approximate eutectics, as clearly indicated by the varying composition of the natural crystals. It seems possible from the recent work that the relation of

[1] Vogt, J. H. L., Die Silikatschmelzlösungen, vol. 1, pp. 157–158, 1903.

[2] Dittler, E., Min. pet. Mitt., vol. 31, pp. 511–522, 1912. (Not read by or accessible to the writer.)

[3] Warren, C. H., Petrology of the alkali granites and porphyries of Quincy and the Blue Hills, Mass. Am. Acad. Arts and Sci. Proc., vol. 49, pp. 317–323, 1913.

the alkali feldspars is not unlike that of the alkali nephelites,[1] both of which exist in two forms; the low temperature and stable form of the potash nephelite gives rise to an unbroken series of mix crystals with the low-temperature form of the soda nephelite, but with the high-temperature form of the soda nephelite it becomes a eutectic.

Albite.—Albite, which usually forms about 10 per cent of the rock, is apparently of two generations, of earlier and of later formation than the microperthite. In a few specimens it occurs in distinct crystals inclosed in the microperthite, and in one slide (No. 2 of specimen 18) one of these crystals is cut by little stringers of albite extending from the surrounding microperthite. The greater part of the albite occurs with quartz in small irregular grains interstitial to the euhedral microperthite and is exceptionally even intergrown with quartz. Apparently, therefore, the greater part of the albite has crystallized later than the microperthite. This is a reversal of the theoretical order of crystallization of albite and microperthite, the microperthite being considered as a eutectic mixture of albite and orthoclase and the albite as the mineral in excess. Similar crystals of albite, of later crystallization than the microperthite, occur in the Quincy granite of the Quincy area and have been explained by Warren[2] as due in part to the excess over the eutectic proportions of that constituent in the original mix crystals which was set free during the unmixing of the mix crystals and thus became active during the last stages of crystallization. Furthermore, it is probable that the increase of gaseous content in the magma caused by the crystallization of the mineral constituents of the granite changed the conditions of equilibrium to such an extent that an excess of pure albite remained after all the potash feldspar had crystallized. The albite may have been dissolved in the gaseous matter. This tendency for unmixed minerals to separate from magmas high in gases has been noted by Iddings[3] and is noted again in this report in connection with the apophysal phases of the granite. (See p. 82.)

Quartz.—The quartz content of the granite varies considerably, and through its decrease the granite passes into the syenitic facies of the alkaline batholiths. The granite in all the areas mapped (see Pl. II), except possibly in one or two insignificant patches, contains from 15 to 50 per cent of quartz. The most important area of granite with a quartz content less than 15 per cent is the north end of the small Marblehead stock. Granite with quartz over 40 per cent is found only locally, usually near the contacts of the Peabody stock. The average is very nearly 25 per cent.

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[1] Bowen, N. L., The sodium-potassium nephelites: Am. Jour. Sci., 4th ser., vol. 43, pp. 115–132, 1916.
[2] Warren, C. H., op. cit., p. 323.
[3] Iddings, J. P., Igneous rocks, vol. 1, p. 231, 1909.

The quartz is interstitial and invariably occurs in anhedral grains, made up of numerous individuals which penetrate and include each other. The quartzes are minutely fractured but, although fractured, usually have a sharp extinction and are in marked contrast to the greatly fractured and strained quartzes of the Dedham granodiorite. The quartz is quite clear but contains minute liquid or gaseous inclusions, generally scattered but in places in irregular trains.

Katophorite (green hornblende).—The principal mafic mineral of the Peabody stock of Quincy granite is commonly an olive-green amphibole ranging from 2 to 6 per cent, the average being 3.5 per cent. The amphibole has strong pleochroism and absorption; $\mathfrak{a}$ = dark olive-green, $\mathfrak{b}$ = dark greenish brown, $\mathfrak{c}$ = greenish brown. The extinction angle on the 010 face is 30°, the axial angle is small, and the mineral is positive. It therefore corresponds with the hornblende of the Cape Ann stock described by Washington.[1] Although the amphibole differs in color from all of the described katophorites it is optically identical and is therefore considered as katophorite. That it is an iron-rich, magnesia-poor amphibole is certain.

Hedenbergite.—The hedenbergite is a pale-green pyroxene with a weak to moderately strong pleochroism; $\mathfrak{a}$ = light grass-green, $\mathfrak{b}$ = lighter green, $\mathfrak{c}$ = yellowish green. It is positive, with an extinction angle of less than 50°. The pleochroism resembles that of aegirite-augite, but the mineral is as a rule lighter colored and the extinction angles are invariably smaller. The Quincy granite of the Peabody stock contains only 0.02 per cent of magnesia, so that it is impossible for the augite molecule to be present in any significant amount. The pyroxene is therefore probably hedenbergite.

Hedenbergite is invariably present but in the Peabody stock forms only about 0.2 per cent by volume. In the granite of Beverly and Manchester hedenbergite is the principal mafic constituent, forming as much as 3 per cent of the rock. Katophorite is invariably present, however. Hedenbergite is known to be present in the pegmatite from Cape Ann, having been determined by Palache.[2]

Colorless pyroxene (?).—In many specimens the katophorite surrounds or is otherwise intimately associated with the hedenbergite. In these specimens the minerals are commonly separated by a colorless mineral which appears to be transitional into hedenbergite and to form part of the hedenbergite-centered crystals. It also has the birefringence of pyroxene, but some of it appears to have diagonal cleavage which greatly resembles the amphibole cleavage. As the mineral forms a reaction zone between the katophorite and hedenbergite it is most probably a pyroxene.

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[1] Jour. Geology, vol. 6, p. 791, 1898.

[2] Oral communication; also described in paper read on the pegmatite at Rockport, Geol. Soc. America, winter meeting, Boston, 1909.

Basaltic hornblende.—The most important accessory of the Quincy granite of the Peabody stock is a deep-brown basaltic hornblende, which forms 0.6 per cent by volume of the rock. The hornblende has a very strong absorption, a being almost black, and thus the determination of its optical properties is impossible in an ordinary thin section. It has, however, a distinct amphibole cleavage and a small extinction angle and is probably basaltic hornblende.

Biotite.—Biotite is rarely primary in the Quincy granite. A brown biotite occurs, however, in small flakes in the cracks of the mafic minerals and surrounding them. It is especially well developed where magnetite and hedenbergite occur together, being doubtless of secondary origin and chiefly derived by the alteration of the hedenbergite. In some varieties of the granite an olive-green biotite occurs, the primary or secondary origin of which is doubtful. Cryophyllite and annite, two rare varieties of a magnesia-poor biotite, have been described by Cooke [1] from the Quincy granite of the Cape Ann area. Washington notes the occurrence of two varieties of biotite in the Cape Ann stock, which he believes to correspond to these two rare types.[2]

Zircon.—Zircon is unusually abundant (0.15 per cent by volume). It occurs in small rectangular grains.

Allanite (?).—A dark reddish-brown mineral occasionally found in the granite of the Peabody stock may be allanite. Its optical properties can not be determined. Allanite is known to occur in the alkaline granites of Essex County and has been described by several writers.[3]

Glaucophane (?).—Irregular shreds and needles, in many places fibrous, of a blue amphibole, which appears to be glaucophane, surround and in many specimens form a fringe around the katophorite. The supposed glaucophane is invariably associated in this manner with katophorite and is also closely associated with the secondary biotite. It is probable, therefore, that it is secondary. This same occurrence is described from the granite of the Cape Ann stock by Washington, who considers the blue hornblende to be secondary, although in other rocks of the region he believes it to be primary.[4] Riebeckites, with a similar habit and occurrence, are found in the Quincy granite outside of Essex County and are considered by Warren [5] to be secondary.

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[1] Cooke, J. P., Am. Jour. Sci., 2d ser., vol. 43, p. 217, 1867; also, Clarke, F. W., and Riggs, R. B., Am. Jour. Sci., 3d ser., vol. 32, p. 358, 1886.

[2] Washington, H. S., Jour. Geology, vol. 6, p. 791, 1898.

[3] Idem, pp. 792–793.

[4] Idem, p. 791.

[5] Warren, C. H., Petrology of the alkali granites and porphyries of Quincy and the Blue Hills, Mass.: Am. Acad. Arts and Sci. Proc., vol. 49, pp. 216–220, 1913.

CHEMISTRY AND CLASSIFICATION.

The chemical analysis of the Peabody stock of the Quincy granite is given below, with analyses of the granite at Rockport and other areas for comparison.

Analyses of Quincy granite and average composition of six specimens from that stock.

	1	2	3	4
SiO_2	71.90	77.61	73.93	73.8
Al_2O_3	12.98	11.94	12.29	13.4
Fe_2O_3	.81	.55	2.91	.8
FeO	2.85	.87	1.55	1.4
MgO	.02	Trace.	.04	.1
CaO	1.04	.31	.31	.3
Na_2O	4.19	3.80	4.66	5.1
K_2O	5.60	4.98	4.63	4.9
H_2O+	.20	.23	.41	
H_2O-	.20	Trace.		
TiO_2	.34	.25	.18	
P_2O_5	.04			
MnO	.08	Trace.	Trace.	.1
BaO	Trace.			
ZrO_2	.12			.1
SrO	Trace.			
	99.87	100.54	100.91	100.0
Specific gravity	2.651	2.618	2.642	

1. Peabody stock, Old quarry, South Lynnfield. M. F. Connor, analyst. Washington, H. S., U. S. Geol. Survey Prof. Paper 99, pp. 114–115, 1917.
2. Hornblende granite, Rockport, Cape Ann. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 793, 1898.
3. Riebeckite granite. Hardwicke quarry, Quincy. H. S. Washington, analyst. Am. Jour. Sci., 4th ser., vol. 6, p. 181, 1898.
4. Average calculated composition of the Quincy granite of the Peabody stock from Rosiwal determinations on six representative rocks of that stock. Pearce, J. S., and Robinson, B. A., thesis, Massachusetts Inst. Tech., 1909.

The norms of the Quincy granite are as follows:

Norms of the Quincy granite.

	1	2	3
Quartz	22.80	35.46	28.98
Orthoclase	33.36	29.47	27.24
Albite	35.11	31.96	37.20
Anorthite		.83	
Acmite	.46		1.85
Diopside	4.71	.65	1.46
Hypersthene	1.85	.26	.13
Magnetite	.93	.93	3.25
Ilmenite	.61	.46	.30

1. Peabody stock; calculated by H. S. Washington. U. S. Geol. Survey Prof. Paper 99, p. 115, 1917.
2. Rockport, Cape Ann; calculated by H. S. Washington. Idem, p. 115, 1917.
3. Quincy area; calculated by H. S. Washington. Idem, p. 117.

The norms of the three rocks all fall into the subrang liparose, although the norm from the granite from Rockport is extremely quaric, so that it is transitional into alaskose. The classification of the three rocks is as follows: Peabody stock, I″.4.1.3, femic liparose; Rockport, I.(3)4.1.3, alaskose-liparose; Quincy, I″.4.1.3″, femic, sodic liparose.

The modes of the same three rocks have also been determined as follows:

Modes of Quincy granite from Peabody, Rockport, and Quincy.

	1	2	3
Quartz	24.5	35.5	30.2
Microperthite	57.7		
Orthoclase		28.2	27.2
Albite	13.2	32.0	27.7
Anorthite		.5	
Total feldspar	70.9	60.7	55.9
Biotite		1.3	
Hornblende (katophorite)	3.5	2.0	
Basaltic hornblende	.6		
Riebeckite			12.3
Glaucophane			2.0
Accessories	.23	.5	.6

1. Average of eight representative rocks of the Peabody stock, the mineral composition being determined by the Rosiwal method. Pearce, J. S., and Robinson, B. A., thesis, Massachusetts Inst. Tech., 1909.
2. Rockport, Cape Ann. Washington, H. S., Jour. Geology, vol. 6, p. 794, 1898.
3. Quincy area. Washington, H. S., Am. Jour. Sci., 4th ser., vol. 6, p. 181, 1898.

The analyses show that the granite of the Peabody stock, although similar to the granite at Quincy and Rockport, is more syenitic, although not greatly different from the granite of the Quincy area in silica and quartz. The granite of Rockport is a quartz-rich facies of the alkaline granites of Essex County, and that of the Peabody stock is a much more representative type.

ALTERATION.

In the fresh, unweathered granite of the Peabody stock the quartzes extinguish sharply and the feldspars have been very little altered. The original mafic minerals have in many places given rise to the secondary minerals described above. Although ordinarily the alteration is slight, in places the original mafic minerals have apparently been fractured and greatly altered, so that irregular patches of primary and secondary minerals occur intimately intermixed with one another. As the feldspars are relatively unaltered it does not seem as if this alteration was caused by secular weathering of the crystallized granite. It is more probable that even before the magma had completely crystallized some of the mafic constituents became unstable and were converted into other minerals.

VARIATION IN EAST DANVERS.

Near the boundary between Danvers and Beverly, north of Folly Hill, there occurs a decided variation of the normal Quincy granite. Owing to the lack of outcrops its extent has not been determined nor is its relation to the normal granite known. It weathers reddish and is finer grained (medium grained) than the normal granite, with less conspicuous euhedral feldspars. It is also richer in dark minerals, chiefly hornblende.

The essential minerals are albite, orthoclase, microcline, microperthite, quartz, green soda and iron-rich hornblende, and biotite. The accessories are zircon and apatite. It is very slightly altered, and the secondary minerals are biotite, chlorite, and kaolin. The feldspars are very different from those of the normal granite. Albite, orthoclase, and microcline occur chiefly as separate grains, not largely intergrown as in normal granite. The microperthite is not only less abundant but is more irregular and patchy, and microcline more commonly than orthoclase is intergrown with the albite. The mafic constituents are much more abundant and form nearly 20 per cent of the rock. They consist of an olive-green, strongly pleochroic hornblende, similar to but not identical with the katophorite of the normal granite, and a strongly absorptive and pleochroic, light-yellowish to greenish-brown and almost black olive-green biotite, which is nearly as plentiful as the hornblende. Some of the biotite is clearly secondary after the hornblende, but much of it is undoubtedly primary.

This granite is closely related to the normal Quincy granite and is a differentiate from the same magma. It is similar to the Squam granite which apparently forms an intrusive mass into the normal granite. Both the Squam granite and that from East Danvers have a strong general resemblance to the fine and medium grained types that form dikes in the normal granite.

APOPHYSAL VARIETIES.

The numerous apophyses which extend from the main granite stocks into the country rock consist of granite, aplite, and pegmatite.

Granites.—Much of the granite of the apophyses is indistinguishable from that of the stocks. It is usually red in color, being more weathered and altered than the normal granite, and is medium to coarse in grain, with euhedral feldspars. The feldspars are chiefly microperthite but are less regularly intergrown. Albite is more abundant and is more broadly twinned. Microcline occurs as separate grains but in small amounts. The mafic minerals are less abundant. A green hornblende is the chief mafic constituent, and a green biotite is probably a primary mineral.

Aplites.—The granite of the apophyses passes into true aplite, which is dense to fine grained and is usually red. The fine-grained aplites are composed almost entirely of quartz and feldspar. Parts even of the same aplite dike are much coarser than others and contain hornblende, biotite, and other mafic minerals. The essential minerals are quartz, microcline, and microperthite. The microperthite is irregularly intergrown and is composed chiefly of orthoclase. A green hornblende and a green biotite, with magnetite and zircon, are the chief accessories. In the finer-grained portions the structure is anhedral, but in the coarser portions it is subhedral. As a rule the-

aplites are more altered than the normal granite. The chief secondary minerals are chlorite, sericite, and kaolin.

Some of the aplites are porphyritic. The phenocrysts are microperthite and are surrounded by a wide zone of quartz and feldspar intergrown micrographically. The groundmass is similar to that of the normal aplites.

The aplites, especially one near Bass Rocks, Gloucester, which has a finer grained and slightly more feldspathic medial portion, are described by Washington.[1] The composition of the aplite dike as a whole he gives as follows:

Analysis of rock from aplite dike near Bass Rocks, Gloucester.

SiO_2	77.14
Al_2O_3	12.24
Fe_2O_3	.29
FeO	1.04
MgO	.06
CaO	.35
Na_2O	4.64
K_2O	4.47
H_2O	.14
TiO_2	.29
MnO	Trace.
	100.66

In the "trap rock" quarry northwest of Peabody the Salem gabbro-diorite is cut by wide dikes of a microcline granite aplite. This aplite is a medium-grained light flesh-colored rock and consists of rarely euhedral pink feldspar and an equal amount of round-grained quartz.

The feldspar is chiefly microcline, which occurs in very irregular grains, closely locked and somewhat intergrown with quartz, many grains of each being included in the other. The microcline, however, more generally incloses the rounded quartzes, and it also incloses small grains of albite. The proportion of the three minerals is about quartz 40 per cent, microcline 50 per cent, and albite 10 per cent. The original mafic minerals formed less than 0.5 per cent of the rock, and only a few small grains of magnetite and shreds of chlorite indicate the presence of hornblende or biotite.

Although unique, the microcline granite aplite is doubtless directly related to the granite of the Peabody stock. It occurs only 300 to 400 yards from the stock, and normal aplites and granite dikes cut the gabbro-diorite in the immediate neighborhood.

Pegmatites.—Relatively fine grained pegmatite dikes, with an average grain of about 2 centimeters, are associated with the other

[1] Jour. Geology, vol. 7, pp. 105–108, 1899.

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apophysal types, cutting the contact phases of the granite and the contact breccias. The pegmatites consist essentially of quartz and feldspar. The feldspar is chiefly microperthite and consists largely of orthoclase but also includes large grains of albite. The larger feldspars are commonly euhedral, and much of the quartz and feldspar is graphically intergrown. Micropegmatite or micrographic structure is, however, not common. The dark minerals are present in very small amount, and the only original mineral is a green biotite, possibly the lepidomelane, annite.[1]

The most conspicuous feature of the pegmatite apophyses is the fact that they carry a medial portion of quartz. Even in a dike a foot wide the central portion, possibly 2 inches wide, may consist of pure quartz. The margins are largely feldspathic, or of feldspar graphically intergrown with quartz. The quartz of the central portion of the pegmatites is like that of the normal granite. As the quartz is strained, minutely fractured, has a wavy extinction, and contains small gas or liquid inclusions, it probably crystallized as the β form above 575° C.[2] The pegmatites also pass into fine-grained aplites, so that the same dike may be aplite in some places and pegmatite in others.

These differences in grain and in mineral association appear to be best explained by a variation in the intruding magma, which, if relatively rich in gases, should crystallize as a pegmatite and, if relatively poor, as an aplite. Again, by the separation of feldspar and quartz from the gas-rich portion, the magma must have been still further enriched in gases, which would retain considerable silica in solution, and this, upon further cooling of the magma and the consequent loss of the gases, would be deposited in the central part of the apophysis. A similar explanation has been advanced by Iddings[3] for the marginal crystallization of pure feldspar around spherulites of intergrown quartz and feldspar. Here a change took place in the physical conditions under which the spherulites of quartz and feldspar were crystallized, "and the change of condition most likely to take place in a cooling magma, from which feldspar and quartz are separating, is a change in the relative amount of gas in the residual liquid magma, provided there is no means of escape."

PERIPHERAL PHASES.

Near the contact of the granite with its syenitic differentiates and with the country rock into which it was intruded there is an irregular zone of porphyritic granite, which is cut by large irregular dikes of

[1] Cooke, J. P., Am. Jour. Sci., 2d ser., vol. 43, p. 217, 1867.
[2] Wright, F. E., and Larsen, E. S., Quartz as a geologic thermometer: Am. Jour. Sci., 4th ser., vol. 27, pp. 421-447, 1909.
[3] Iddings, J. P., Igneous rocks, vol. 1, p. 231, 1909.

fine to medium grained granite, called for the sake of distinction "fine-grained" granite. The "fine-grained" granite dikes, although confined for the greater part to the contact zones, cut the normal granite also.

The porphyritic granite is not developed to any great extent in the Peabody stock, nor in the small stocks of Lynn, Swampscott, and Marblehead, but is largely confined to the granite of Beverly and Manchester. The largest area (see Pl. II, in pocket) is in East Beverly, north of Beverly Farms, where it is near the contact with the syenite trough which extends from Coys Pond in east Wenham to Essex. Other smaller areas occur along the coast from Beverly to Gloucester.

The rock is medium to coarse grained, with phenocrysts of feldspar, some of which measure 2.5 by 1 centimeter. A black hornblende is abundant but does not occur as phenocrysts. Except for its porphyritic texture the rock is similar to the normal granite, and the minerals are identical, although the mafic minerals are more abundant and quartz is lower in the porphyritic variety. In general the porphyritic granite appears to be much more altered than the normal granite, weathering red. The feldspars have been sericitized, and yellowish-brown and green secondary biotites occur.

The "fine-grained" granite is almost as restricted in its occurrence as the porphyritic granite. However, dikes of it occur throughout all the granite areas, although largely confined to the neighborhood of the contacts.

The "fine-grained" granite is light gray, weathering to yellowish red, varies irregularly and rapidly from fine to medium grained, and in places has a subporphyritic texture. It is composed largely of feldspar and quartz, with a small percentage of dark minerals. The essential minerals are quartz, microperthite, albite, orthoclase, microcline, and brown biotite. The accessory minerals are those of the normal granite. The feldspar differs greatly in different parts of the granite but is chiefly microperthite, which in some of the subporphyritic varieties is an intergrowth of microcline and albite. However, in the finer-grained, quartz-rich varieties of the granite microcline is the chief feldspar and microperthite may be missing. Quartz is as abundant as in the normal granite. The feldspars and quartz occur in closely locked anhedra, in places intergrown micrographically, although the quartz occurs in large irregular grains also, and the feldspars in some of the coarser-grained varieties of the granite are euhedral and some of them are intergrown with quartz around their margins.

The chief mafic minerals are a brown biotite, which occurs in small rectangular flakes, and a green strongly pleochroic mica with a high birefringence. The green mica is altering to chlorite

The "fine-grained" granite types resemble the porphyritic, hornblende-biotite granite (Squam granite) of the intrusive stock, occurring along Squam River in Gloucester.

SCHLIEREN.

Schlieren are common in the Quincy granite, especially in Beverly and Manchester. They occur abundantly in the granite of Cape Ann also, from which they have been described by Washington.[1] The schlieren closely resemble the "fine-grained" granites and are virtually identical in appearance. Quartz, albite, microcline, and microperthite are present in all of them, and microperthite occurs in some of them as euhedral phenocrysts. The mafic minerals in the schlieren are the same as those of the granite in which the schlieren occur but are slightly more abundant, and the minor accessories are less abundant. Although the contact of the schlieren with the inclosing granite is well defined, it is seen on microscopic examination that the crystals of the schlieren and of the granite are dovetailed.

Washington gives the analysis of a schliere, which is apparently more basic than most of those occurring in the Cape Ann stock but which yet does not differ greatly from the granite. The analysis should be compared with that of the granite of the Peabody stock rather than with Washington's analysis of the granite at Rockport, as the latter is more siliceous than the normal granite of the Cape Ann stock.

Analysis of a schliere of the Quincy granite at Rockport.[2]

SiO_2	67.35
Al_2O_3	15.05
Fe_2O_3	1.23
FeO	4.76
MgO	.03
CaO	.55
Na_2O	4.42
K_2O	6.08
H_2O+	.17
H_2O-	.16
TiO_2	.60
MnO	.05
	100.45
Specific gravity	2.69

The relatively high potash indicates that the potash feldspar, microcline, predominates over the albite. The schliere is also, as Washington points out, less siliceous. The process of separation, or differentiation, of such small portions of magma from a parent magma

[1] Jour. Geology, vol. 6, pp. 794-796, 1898.

[2] Quartz syenite (schliere in granite), Pigeon Hill quarry, Rockport. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 795, 1898.

so nearly of the same composition, is extremely difficult to explain. Unless the gas content had a controlling influence, it does not seem that the ordinary immiscibility or liquation hypothesis as argued by Loewinson-Lessing [1] would hold.

BEVERLY SYENITE.

SUBDIVISIONS.

The Beverly syenite includes the alkaline syenites of Beverly, Manchester, Salem, and Marblehead, comprising pulaskites and umptekites. Both these varieties, together with nordmarkite (which is here not included in the Beverly syenite but mapped separately), have been described as occurring in Essex County, pulaskites and nordmarkites by Washington [2] and umptekites by Wright.[3] The three varieties are closely related. In Essex County all occur under similar conditions and are clearly transitional. It seems best to follow Rosenbusch [4] and to consider the lack or presence of quartz as the principal difference between pulaskite and nordmarkite. This distinction had already been proposed by Daly [5] and is borne out by the average analyses calculated by him.[6] All petrologists agree as to the definition of umptekite—that is, it is an alkaline syenite in which the chief femic mineral is an alkali-rich amphibole. Difficulty is met in classifying some of the rocks of Essex County as umptekites or pulaskites, for alkali-rich hornblende enters into the composition of the normal aegirite pulaskite, and such rocks are transitional into umptekite, in which aegirite is of minor importance. The writer has preferred to group the great majority of the alkaline syenites of the area (not of Essex County as a whole) as pulaskites, classifying as nordmarkites only those varieties which contain essential quartz (at least 2 to 3 per cent), and as umptekites those varieties in which the alkaline amphibole is distinctly in excess over the other mafic minerals. Washington[7] came to virtually the same decision.

PULASKITE.

Distribution and subdivisions.—The pulaskites occur chiefly in Beverly, north of Beverly Cove, and along the Beverly-Manchester shore from a point south of Pride's station nearly to Manchester Harbor. In these two areas they are coarse-grained massive rocks and are comparatively free from inclusions of the country rock into which the alkaline rocks were irrupted. They occur also on Salem

1 Loewinson-Lessing, F., Studien über die Eruptivgesteine: Cong. géol. internat., 7e sess., Compt. rend., pp. 193–464, 1897.
2 Washington, H. S., Jour. Geology, vol. 6, pp. 799, 801, 804, 1898.
3 Wright, F. E., Min. pet. Mitt., vol. 19, p. 308, 1900.
4 Rosenbusch, H., Mikroskopische Physiographie der Mineralien und Gesteine, pt. 2, pp. 146–147, 1907.
5 Daly, R. A., The geology of Ascutney Mountain, Vt.: U. S. Geol. Survey Bull. 209, p. 70, 1903.
6 Daly, R. A., Am. Acad. Arts and Sci. Proc., vol. 45, p. 220, 1910.
7 Op. cit., pp. 804–807.

Neck, in the contact breccias of gabbro-diorite and syenite along the northern shore of Marblehead, in South and North Salem, and in the breccia zone north of the Peabody stock of Quincy granite on Mount Pleasant.

The pulaskites are themselves divided into two types, the more abundant a coarse-grained normal variety, and the less abundant a variety with trachytic texture, confined for the greater part to apophysal phases and large dikes and sheets.

Normal pulaskites.—The normal pulaskite is a light or yellowish gray coarse-grained rock, consisting largely of feldspar and of dark minerals that in some varieties are insignificant. The feldspars occur in tabular grains diversely arranged. The dark minerals occur as euhedral grains and also in the interstices of the tabular feldspars.

The essential minerals are microperthite and a grass-green aegirite, the latter being in some occurrences only accessory. The accessory minerals are albite, a green alkali-rich amphibole, similar to the katophorite of the Quincy granite, diopside, magnetite, and rarely a colorless titanite. Minor accessories, such as zircon and apatite, which are common in the Quincy granite, are rare or absent. A yellow biotite may be in part original. The secondary minerals are a yellowish-brown biotite, a yellowish-green lepidomelane, some chlorite, calcite, sericite, and kaolin. The microperthite occurs as long, tabular, and in many places interlocking crystals, and also in the interstices. It is composed of nearly equal amounts of orthoclase and albite (or albite-oligoclase). The intergrowth, which is much finer and less regular than that of the Quincy granite, is microperthite varying to cryptoperthite. The alteration of the pulaskite is slight. The aegirite, hornblende, and diopside have altered to yellowish-brown biotite (lepidomelane), chlorite, and calcite. The feldspars, especially the orthoclase portion of the microperthite, are only slightly clouded with sericite and kaolin.

Many of the apophysal phases of the alkaline syenites are identical with the pulaskite. As a rule they are more altered, the mafic minerals having largely gone over to chlorite and calcite. Sericite is also more abundant and occurs in small flakes. In some of the apophyses the rock has been greatly crushed and has weathered to a reddish color. Secondary microcline and albite occur, and the remnant microperthite is greatly altered. Epidote occurs with the secondary green biotite and chlorite.

The normal pulaskite differs greatly in grain, passing into very coarse grained varieties and pegmatites, which usually occur as large, irregular veins and segregations. They consist chiefly of microperthite in elongate, rectangular prisms, many of them 12 by 3 centimeters square. The mafic minerals are principally magnetite and aegirite and occur in the interstices of the feldspars. Hornblende and

biotite are also present, the latter chiefly as narrow rims around the magnetite. Mafic minerals also occur in narrow discontinuous veins, many as much as 3 to 4 centimeters wide, which cut the feldspars. Similar veinlike segregations of the mafic minerals occur in some of the normal alkaline syenites and rarely in the Quincy granite.

The pulaskites have younger aplitic phases which cut the basic dikes that cut the normal pulaskite. They are fine to medium grained and are composed of tabular feldspars with a diverse arrangement and with interstitial dark minerals. The feldspar is principally microperthite or cryptoperthite, but albite-oligoclase also occurs, especially between the larger euhedral microperthites, which often have irregular and crushed edges. The chief mafic mineral is a brown biotite, with magnetite and apatite accessory. A secondary green biotite or lepidomelane appears to have been derived from a green pyroxene.

Hedrumitic pulaskites.—Pulaskites with a trachytic texture have been called hedrumitic pulaskites, or hedrumites, by Brögger.[1] Such rocks occur in Essex County and have been described by Washington[2] as hedrumitic pulaskites. They occur as apophyses and large dikes or sheets that are somewhat younger than the normal pulaskites.

The ordinary hedrumitic pulaskite is light gray and weathers brownish yellow. It is medium grained and composed chiefly of feldspar, which occurs in relatively thin plates in parallel arrangement. The dark minerals are fine grained and occur irregularly scattered through the rock.

The essential minerals are microperthite and aegirite. The accessory minerals are albite and microcline, brown biotite, an olive-green amphibole similar to the amphibole of the umptekite, and magnetite. The amphibole occurs around the magnetite and aegirite and has doubtless been derived in part from them but probably under magmatic conditions, for the contact of the minerals is sharp and there is little evidence of ordinary alteration. The chief secondary mineral is a dark-green lepidomelane.

A light-gray porphyritic rock, otherwise similar to the ordinary hedrumitic pulaskite, occurs as dikes and apophyses. The groundmass is finer grained than in the ordinary hedrumitic pulaskite, and the trachytic texture is not so pronounced megascopically. The large, perpatic phenocrysts are of feldspar. The constituent minerals are similar to those of the ordinary hedrumitic pulaskite, but the mafic minerals are more abundant. The phenocrysts are microperthite, and, although their boundaries are sharp, many of them include small, rounded grains of aegirite.

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[1] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, vol. 3, p. 183, 1897.
[2] Op. cit., p. 808.

Chemical composition.—The analyses given below include those of the pulaskite, umptekite, and nordmarkite.

Analyses of Beverly syenite and other alkaline rocks and average composition of similar rocks.

	1	2	3	4	5	6	7	8
SiO_2	63.09	63.71	62.99	66.60	68.36	61.86	64.36	61.96
Al_2O_3	18.44	18.30	14.25	15.05	15.58	19.07	16.81	17.07
Fe_2O_3	2.90	2.08	2.78	1.07	.90	2.65	1.08	2.35
FeO	1.36	2.52	5.15	4.42	3.24	1.49	2.71	3.37
MgO	.16	.09	1.30	1.36	.45	.55	.72	1.38
CaO	1.00	1.18	2.72	2.21	1.85	41.47	1.55	3.41
Na_2O	7.25	6.39	4.86	4.30	3.97	6.45	5.76	4.65
K_2O	5.23	6.21	6.35	5.42	5.27	5.75	5.62	3.80
H_2O+	.62	.17	.18	.41	.17	.47	.70	.93
H_2O-	.21	.09			.18			
TiO_2	.45	Trace.	.16	.76	Trace.	.15	.45	.99
P_2O_5						.08	.09	
MnO	Trace.	Trace.	.18	Trace.	Trace.	.01	.15	.09
BaO								
	100.77	100.74	100.92	100.33	100.97	100.00	100.00	100.00
Specific gravity			2.732	2.612				

1. Pulaskite (Beverly syenite of writer), Salem Neck, Mass. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 806, 1898.
2. Hedrumitic pulaskite (Beverly syenite of writer), Salem Neck, Mass. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 806, 1898.
3. Umptekite (Beverly syenite of writer), Curtis Point, Beverly, Mass. F. E. Wright, analyst. Min. pet. Mitt., vol. 19, p. 318, 1900.
4. Akerite (nordmarkite of writer), Gloucester, Mass. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 798, 1898.
5. Nordmarkite (Squam granite of writer), Wolf Hill, North Gloucester, Mass. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 800, 1908.
6. Average pulaskite. Daly, R. A., Am. Acad. Arts and Sci. Proc., vol. 45, p. 220, 1910.
7. Average nordmarkite. Idem.
8. Average akerite. Idem.

The analyses of the two pulaskites are similar, and they do not differ greatly from Daly's average analysis of pulaskite.

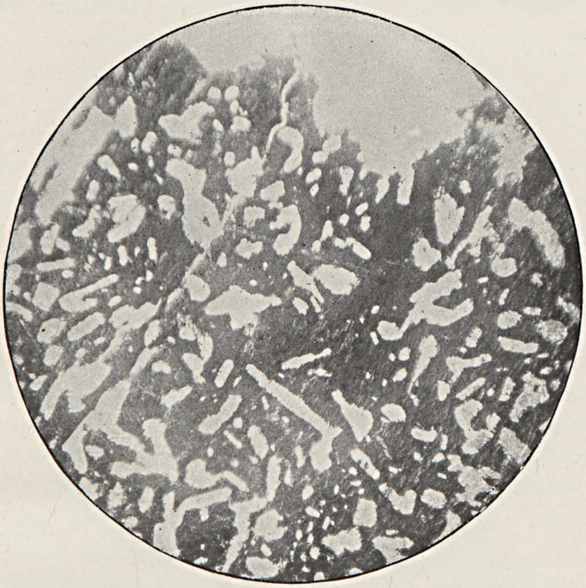
UMPTEKITE.

By an increase of the green alkali hornblende and a corresponding decrease of aegirite the pulaskites pass into umptekite. Some of the hedrumitic pulaskites of Salem Neck pass into umptekite and yet retain their trachytic texture. The normal umptekites, however, do not have a pronounced trachytic texture, and they are more closely allied to the normal pulaskites. The umptekites occur as irregular intrusives in the contact-breccia zone of the pulaskites exposed on the shores of Beverly and Manchester.

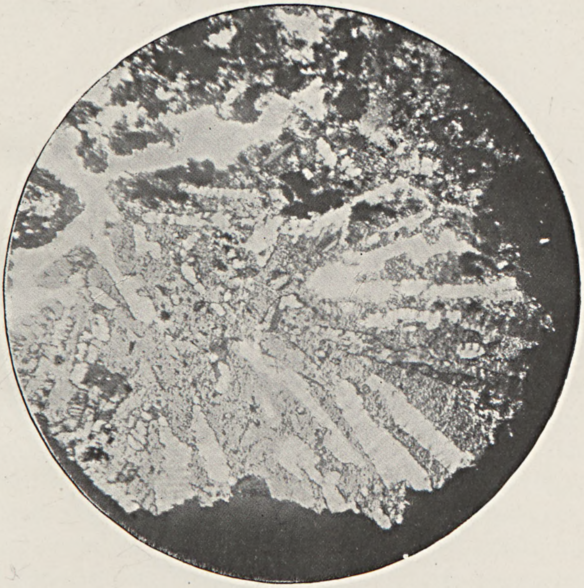
The umptekite is a light medium-grained flesh-colored rock that consists largely of feldspar. The feldspar is somewhat tabular with a diverse to subparallel arrangement. Most conspicuous are large irregular grains of hornblende and biotite, some as large as 1 centimeter in diameter, which are scattered through the rock and which envelop the narrow lath-shaped or tabular feldspars.

The essential minerals are microperthite, a green hornblende, and green lepidomelane. Wright [1] has determined the optical proper-

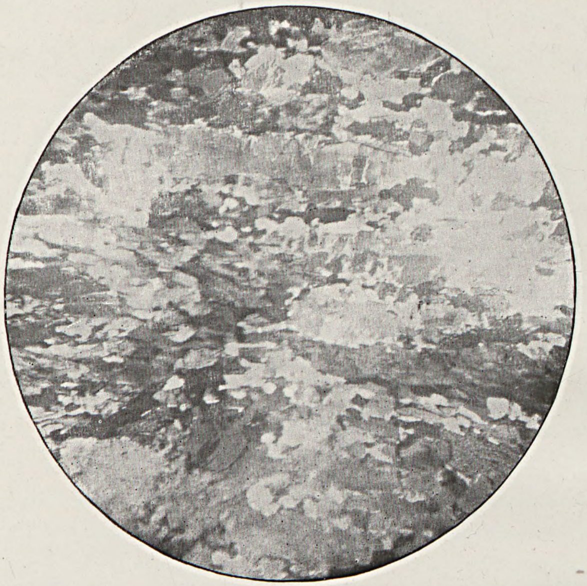
[1] Wright, F. E., Min. pet. Mitt., vol. 19, p. 308, 1900.



A. PHOTOMICROGRAPH OF UMPTEKITE, SHOWING POIKILITIC LEPIDOMELANE WITH DIVERSELY ARRANGED FELDSPAR CHADACRYSTS.



B. PHOTOMICROGRAPH OF UMPTEKITE, SHOWING POIKILITIC HORNBLENDE WITH RADIALLY ARRANGED FELDSPAR CHADACRYSTS.



A. PHOTOMICROGRAPH OF NEPHELITE SYENITE (FOYAITE), SHOWING TRACHYTIC TEXTURE.

B. PHOTOMICROGRAPH OF NEPHELITE SYENITE FROM A POINT NEAR THE CONTACT WITH GABBRO, SHOWING POIKILITIC SECONDARY BIOTITE.

ties of the hornblende as follows: $\gamma-\alpha=0.0222$, $\gamma-\beta=0.0013$, $\beta-\alpha=0.0209$, $\mathfrak{c}$: $c=20.5°$; $2V$=about 36°; $\mathfrak{a}$=greenish yellow, $\mathfrak{b}$= olive-green, $\mathfrak{c}$=blue-green. The accessory minerals are diopside and ilmenite. The distinctly secondary minerals are brown biotite and muscovite. The hornblende and biotite surround the diopside and include the lath-shaped feldspars poikilitically. The included feldspars—that is, the chadacrysts [1]—are dominant. The chadacrysts are medium sized, and although most of them are diversely arranged (Pl. IV, *A*), some are radially arranged (Pl. IV, *B*). The hornblende and lepidomelane oikacrysts [1] were apparently developed considerably later than the feldspar and diopside crystals.

The umptekite is confined to the contact zones where gabbro-diorite inclusions occur. From its general similarity in appearance and occurrence to the hybrid rocks the writer believes that it is a hybrid between pulaskite and gabbro-diorite. If this conclusion is correct the materials of the hornblende and lepidomelane have been derived in part from the intruded gabbro-diorite. The conclusion is supported by the occurrence of olivine, noted by Wright (but not by the writer), in the umptekite, a thing hardly to be expected in a normal differentiate of the alkaline syenites, which are extremely low in magnesia. It is still further supported by the peculiar differences in the chemical composition of the umptekite and pulaskites, which can hardly be explained as a result of ordinary processes of differentiation.

QUARTZ SYENITE OR NORDMARKITE.

Between the alkaline granites and the pulaskites are the nordmarkites. The bulk of the nordmarkites of Essex County, clearly transitional into the normal Quincy granite, are really quartz-poor granites. Like the granite, they occur as part of the main batholith and stocks. Such nordmarkites are not common in the special area, and where they do occur, as at the north end of the small Marblehead stock and in the main Peabody stock, they are too subordinate to be shown on the geologic map (Pl. II). They occur abundantly, however, in the other parts of the county and are shown on the small scale map of Essex County (Pl. I). They are coarse-grained, usually greenish-gray rocks, which on exposure to the air turn darker green like the granites. They are granitic in texture, having the same rectangular feldspars and virtually the same constituent minerals as the Quincy granite. Quartz is of course very much lower, being less than 10 per cent, and diopside is a common accessory mineral. As noted by Washington [2] the feldspars are brecciated around the

[1] Iddings, J. P., Igneous rocks, pp. 202–203, New York, 1909.
[2] Washington, H. S., Jour. Geology, vol. 6, p. 797, 1898.

borders. Microcline and albite occur in the brecciated zone and are possibly secondary.

Nordmarkites of this character have been called akerites by Washington.[1] Akerites, as defined by Brögger,[2] contain considerable plagioclase and are, as Iddings [3] calls them, calcialkalic syenites. Washington does not describe the rocks as containing plagioclase other than albite, and the writer has failed to recognize any other. As seen from the table of analyses of the alkaline syenites (p. 88) the "akerite" of Essex County is richer in silica and lower in lime and magnesia than the average akerite calculated by Daly. It corresponds closely with the average nordmarkite but is a little higher in lime, from the presence of diopside. The writer therefore prefers to consider the rocks under discussion as possibly lime-rich nordmarkites.

Nordmarkites of another type occur in the special area but not in masses large enough to be mapped independently from the other alkaline syenites. They are really quartz-bearing pulaskites and occupy a position intermediate between granite and pulaskite, which in places grade into each other through nordmarkite in a comparatively few yards or even feet. In the special area nordmarkites of this character are confined to the neighborhood of the Beverly and Manchester coast, from Woodbury Point east to Manchester Harbor.

The nordmarkites are medium to coarse grained, although as a rule irregular in grain and texture. When fresh they are light greenish gray, but when exposed they weather to a darker green and to a yellowish brown. Feldspar is the most abundant constituent. It rarely occurs in well-defined euhedral grains but rather in large grains with irregular or poorly defined outlines. Quartz, some of it in large grains, occurs in the interstices. The dark minerals are small and irregular but are fairly abundant, constituting 10 to 15 per cent of the rock which is somewhat higher than in the pulaskites.

The essential minerals are microperthite, albite, orthoclase, hedenbergite, diallage, and quartz. The accessory minerals are an olive-green hornblende (which surrounds the pyroxene), zircon, and magnetite. The secondary minerals include some of the albite, orthoclase, quartz, and hornblende, a colorless pyroxene, actinolite, and chlorite.

All the larger feldspar grains are microperthite. Many of them are surrounded by a crushed zone of small irregular grains of albite and orthoclase, very clear and evidently recrystallized. With the recrystallized albite and orthoclase, and therefore probably secondary,

[1] Op. cit., pp. 796–798.
[2] Brögger, W. C., Zeitschr. Kryst. Min., vol. 16, p. 43, 1909.
[3] Iddings, J. P., Igneous rocks, p. 364, 1909.

is green uralitic hornblende and quartz and the colorless pyroxene, either diopside or augite. Quartz is also primary, occurring in large grains between the microperthites.

The nordmarkite has evidently been greatly metamorphosed, crushed, and recrystallized. The chief agent of the metamorphism has been the granite. The nordmarkite, with its intermediate position between the granite and the slightly older pulaskites, is a kind of contact-metamorphosed phase of the alkaline syenites. It was, however, originally quartz bearing and is a true transitional rock.

SQUAM GRANITE.

The rock along Squam River, which Shaler[1] called quartz diorite and Washington[2] nordmarkite, the writer prefers to consider a basic granite (here called Squam granite), for it contains 25 per cent of quartz. The other constituents are alkaline feldspar, 40 per cent, and femic minerals, principally hornblende and biotite, 35 per cent. The silica is seen from the analysis to be too high and the alkalies too low for nordmarkite. It would be stretching the limits of nordmarkite too far to include a rock with 25 per cent of quartz.

NEPHELITE SYENITE.

Although nephelite-bearing rocks occur both on Salem Neck and along the Beverly and Manchester shore the true nephelite syenites are confined to Salem Neck and (according to Sears[3] and Washington[4]) to Great Haste Island, a small rocky island off Salem Neck. Washington divides the nephelite syenites into the two groups proposed by Brögger,[5] ditroite and foyaite. As Washington states, the two types are transitional, and the great majority of the nephelite syenites have a trachytic texture, which is of course very conspicuous in the typical foyaite. No new information can be added to the very full descriptions of these rocks already published by Washington.[4] The foyaitic variety is a bluish-gray fine to medium grained rock, consisting largely of feldspar and having a pronounced trachytic texture. (See Pl. V, *A*.) As a rule the foyaites are somewhat darker colored and finer grained than the hedrumitic pulaskites. The essential minerals are microperthite, albite, nephelite, and a green hornblende. The accessory minerals are biotite, with a pleochroism ranging from yellow to dark olive-green, a grass-green aegirite, zircon, titanite, and magnetite. Washington notes the presence of

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[1] Shaler, N. S., U. S. Geol. Survey Ninth Ann. Rept., p. 606, 1889.
[2] Op. cit., p. 799.
[3] Sears, J. H., The physical geography, geology, mineralogy, and paleontology of Essex County, Mass., p. 190, Salem, Mass., Essex Inst., 1905.
[4] Op. cit., pp. 801-804.
[5] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, vol. 3, p. 165, 1898.

sodalite and cancrinite. The microperthite, nephelite, and aegirite apparently crystallized earlier than the amphibole and biotite, which occur as elongate crystals between the parallel tabular microperthites. In some varieties there is also a conspicuous development of microperthite phenocrysts.

Where the foyaite is in direct contact with the xenoliths of Salem gabbro-diorite it is usually more coarsely crystalline and contains irregularly scattered small black rounded patches of amphibole and biotite, including the earlier crystallized tabular feldspars and diopside. The microscope shows that the amphibole and biotite are identical with the poikilitic amphibole and lepidomelane of the umptekite. (See Pl. V, *B*.) Like the minerals from the umptekite the amphibole and lepidomelane of the nephelite syenite are apparently of secondary origin, and their materials were probably in part derived from the basic country rock.

Washington has published the following analyses of the nephelite syenites:

Analyses of nephelite syenite.

	1	2
SiO_2	58.77	59.31
Al_2O_3	22.64	22.50
Fe_2O_3	1.54	1.93
FeO	1.04	1.40
MgO	.19	.17
CaO	.74	.46
Na_2O	9.62	7.98
K_2O	4.89	4.08
H_2O+	.90	1.12
H_2O-	.07	.15
TiO_2	.31	.32
ZrO_2	.11	....
MnO	Trace.	Trace.
BaO	None.	....
	100.82	99.42

1. Nephelite syenite (foyaite), Salem Neck. H. S. Washington, analyst. Jour. Geology, vol. 6, p. 803, 1898.
2. Nephelite syenite (ditroite), Great Haste Island. H. S. Washington, analyst. Idem.

STRUCTURAL RELATIONS OF THE PLUTONIC ROCKS.

As is shown by their occurrence and by their chemical and mineral composition, the plutonic types described are all closely related and consequently must have been derived from the same parent alkaline magma. The Quincy granite occurs in the greatest amount, underlying an area about 10 times as large as that underlain by all the other types together. The most characteristic feature of the distribution of the various types is the restriction of all except the normal and fine-grained granite to the marginal zone of the batholith—and even the fine-grained granite fails in the central part of the batholith, except as very small dikes and schlieren. The restriction to the marginal zone of the batholith is clearly shown on the map of the

special area (Pl. II, in pocket). Perhaps the Beverly-Manchester shore, where the syenitic and specialized types of granite have been developed, is not clearly shown to be near the margin; but it doubtless is, for the irruptive rocks here contain numerous large xenoliths of Salem gabbro-diorite and Cambrian or pre-Cambrian metamorphic rocks.

The normal granite nowhere cuts the normal pulaskite, nor does the pulaskite cut the granite. That the two rocks are transitional is clearly shown in some places. The best transition the writer has seen occurs on the shore of West Manchester, one-fourth mile southwest of the railroad station, where the transitional zone is about 150 feet wide. At first quartz occurs in the pulaskite as small grains between the much larger euhedral grains of feldspar; then in small segregations, irregular patches, or small veinlets; and finally as an essential constituent (over 15 per cent). Two hundred yards to the east there is another transition zone, less than 10 feet wide, between the pulaskite and the granite.

Though the two rocks are transitional the metamorphism of the quartz-bearing pulaskite or nordmarkite suggests that the granite is slightly younger than the pulaskite.

The other phases of the alkaline and nephelite syenites occur only in dike form. These dikes or apophyses, chiefly hedrumitic pulaskites and nephelite syenites, cut the normal pulaskite. Their relation to the granite is not clearly shown, but they are probably younger. The porphyritic granite is another peripheral facies of the granite batholith, its characteristic texture being probably due to the special physical conditions which existed at the contact during its crystallization. The normal granite and the porphyritic granite and alkaline syenites are all cut by the "fine-grained" granite, which occurs in distinct dikes with regular walls. The apophysal phases, particularly the aplites and pegmatites, have various relations with the other plutonic types but are usually later, cutting all of them.

ANDOVER GRANITE.

North of Ipswich River in North Reading (Middlesex County) occurs the biotite-muscovite Andover granite. Its relations to the other formations are not shown at North Reading, and as no special detailed work has been done on the Andover granite it is not further discussed here. (See, however, pp. 27–29.)

DIKE ROCKS.

TYPES.

On account of their great number and variety, the dike rocks of the special area have not been given the detailed study that they demand and consequently can not be fully treated here. Neither

can the dikes be represented on the map (Pl. II), for they occur in too great numbers[1] to be shown with much accuracy on so small a scale. Moreover the various rock types can not be distinguished megascopically, almost every dike requiring microscopic study. The dike rocks include many interesting and some new types, and the determination of their lithologic character and structural relations would doubtless add much to existing information concerning the variations of igneous rocks. The dikes, therefore, afford an excellent subject for detailed study. Such study has been begun by J. D. MacKenzie,[1] who has prepared a detailed map of the dikes of West Manchester. Although he has studied the dikes of only a very small area his work has shown that all those related to the alkaline plutonics, from the most felsic to the most mafic, form a transitional series. He has found also a new dike rock provisionally classed as an "amphibole fourchite," whose discovery Washington[2] foreshadowed in 1899 when he wrote:

> It is * * * a somewhat remarkable fact that no typical * * * monchiquites [the "amphibole fourchite" belongs to the monchiquite family] have yet been observed in the region.

For convenience in description the dikes are subdivided into felsic and mafic, the division being virtually that employed by Washington.[3] The mafic dikes are the more numerous.

MAFIC DIKES.

The mafic dikes may be classified as diabase, camptonite, vogesite, kersantite, minette, and "amphibole fourchite."

DIABASE DIKES.

Structural relations.—Great numbers of diabase dikes cut the Lynn volcanics, the subalkaline plutonic rocks, and the contact zones of the alkaline batholiths. They range in size from small offshoots to dikes more than 100 feet wide. So far as known they are all younger than the subalkaline batholith. Some, as already described (see p. 49), are clearly older than the alkaline irruptives and may possibly be genetically related to the subalkaline rocks. Many of the diabases, however, were injected during or directly following the irruption of the alkaline rocks, as is shown by their restriction for the greater part to the contact zones and by the fact that although they cut normal granite and pulaskite they are cut by the "fine-grained" granite and apophysal phases of the granite and syenite. Still other diabase dikes are distinctly younger and may be Triassic in age, being related to the

[1] J. D. MacKenzie (manuscript thesis, Massachusetts Inst. Tech., 1911) maps over 60 dikes on the West Manchester shore within half a mile.

[2] Jour. Geology, vol. 7, p. 284, 1899.

[3] Idem, pp. 469–470.

extrusions and injections of diabase of the Newark group. Although these youngest diabases cut all the alkaline rocks they are not abundant except near the contacts of the alkaline batholiths, probably on account of the unfissured character of the main granite mass. As the diabases are all similar lithologically they are subdivided chiefly on the basis of their structural relations.

Diabase dikes not directly related to alkaline irruptives.—Diabase dikes not directly related to the alkaline irruptives are dark, nearly black rocks, which commonly weather brown. The larger dikes are coarse grained, and nearly all show pronounced "chilling" along their margins. Few of them are porphyritic, although they contain a few small phenocrysts of plagioclase; and a dike exposed in North Malden is glomeroporphyritic with phenocrysts of labradorite, biotite, and augite. The essentials of the groundmass are seen microscopically to be labradorite (about $Ab_{40}An_{60}$) and light-violet to colorless augite. The accessories are magnetite and apatite, often with abundant pyrite. The texture is ophitic, so that the rock is a typical diabase. The alteration varies from slight to very great. The secondary minerals include uralite, biotite, sericite, serpentine, chlorite, and calcite. Those diabases known to be older than the alkaline plutonic rocks because they occur in the Salem gabbro-diorite or the Newburyport quartz diorite and are cut by granite apophyses are very greatly altered; and although they retain their original ophitic texture they have had nearly all their augite converted to uralite and their labradorite sericitized. Rarely, as in a 15-foot dike exposed north of the Wakefield road, one-fourth mile west of North Saugus, they contain quartz in rounded grains, 2 or 3 millimeters in diameter, probably cognate xenocrysts [1] rather than quartz phenocrysts.

Some of the old diabase dikes that were injected into the gabbro-diorite have been brecciated and contact metamorphosed by the alkaline irruptives, more especially by the syenites. Megascopically they are similar to the unmetamorphosed diabases and even microscopically their texture and mineral composition are seen to have been originally the same—that is, nonporphyritic and nonolivine bearing. The ophitic texture is preserved even in profoundly metamorphosed dikes, but the augite of these metamorphosed diabases is surrounded by the brown barkevikite amphibole characteristic of the contact-metamorphosed gabbro. The barkevikite also penetrates the augite, forming little apophyses, which finger into the cracks of the augite. The amphibole has developed also at various centers in the augite, giving it a peculiar spotted appearance. (See Pl. VI, *A*.) Besides the barkevikite, a brownish-green amphibole and a peculiar yellowish to reddish-brown biotite occur.

[1] Harker, Alfred, The natural history of igneous rocks, p. 355, 1909.

Diabase dikes closely related to alkaline irruptives.—The diabases that are related to the alkaline irruptives are similar in appearance to those not related but are usually porphyritic. The phenocrysts, which are of labradorite, are not large nor abundant. The essentia minerals are labradorite and a pale-violet augite. Olivine is an abundant accessory mineral in some of the diabases, the other accessories being magnetite and apatite. The alteration is usually large, the secondary minerals being uralite, chlorite, serpentine, epidote, sericite, muscovite, magnetite, and calcite.

Many of the porphyritic olivine diabases are cut by apophysal and dike phases of the granite and syenite. Where cut by syenite they have been most strongly metamorphosed. Megascopically these metamorphosed varieties resemble the normal olivine diabases except on the weathered surface, which, on account of the large amount of biotite in the rock, has a characteristic brownish color with semimetallic luster. Besides the original minerals and the common secondary minerals the contact-metamorphosed varieties contain a large amount of the barkevikite and the yellow to reddish brown biotite. Where the contact metamorphism is extreme the original pyroxene has been wholly destroyed, and its constituents have apparently been recrystallized to diopside and a greenish-brown amphibole. The feldspar also has been recrystallized into clear anhedral grains, some of which are faintly twinned. It has a pronounced zonal growth from $Ab_{40}An_{60}$ to $Ab_{60}An_{40}$. Yet even in this largely recrystallized type there are traces of the original texture and composition, for olivine has not altered greatly, although surrounded by wide rims of serpentine and magnetite. Other significant secondary minerals are green uralite and common brown biotite.

One type of the diabases related to the alkaline irruptives is characterized by tabular plagioclase phenocrysts, whose average size in thin sections is about 8 to 10 millimeters long by 1 millimeter wide. The dikes of this type are numerous and cut most of the porphyritic olivine diabases but are themselves cut by porphyritic diabases and by some of the apophysal phases of the plutonic types. The groundmass consists of labradorite and pink augite, ophitically intergrown. Magnetite is the only important accessory. The alteration is usually large, the common secondary minerals being uralite, chlorite, sericite, muscovite, and calcite. Where cut by syenite and granite a large amount of secondary greenish-brown hornblende and biotite has been developed, the augite has been converted into a light-green to colorless pyroxene, and the plagioclase has been partly recrystallized, the partly recrystallized feldspars having a zonal structure.

The granite in Manchester and more abundantly toward Gloucester is cut by basic porphyritic dikes with very large phenocrysts of labradorite, some of which measure 10 by 4 centimeters. Some

of the rocks are glomeroporphyritic, with apparent feldspar phenocrysts, the largest of which are a foot or more in length. Only a single dike of this character (9 feet wide) occurs in the special area, at the east end of the Singing Sand beach of Manchester. The groundmass is more feldspathic than that of the normal diabases, and the texture is much more irregular. Augite and primary (?) green hornblende with magnetite and titanite occur with the plagioclase of the groundmass. The rock is ordinarily much altered, especially the feldspar, the secondary minerals being biotite, uralite, sericite, and calcite.[1]

On Salem Neck north of Cat Cove there is a small dike, which cuts all the others at that place. It has a black aphanitic groundmass with phenocrysts of labradorite and augite. Megascopically it resembles a fine-grained lamprophyre, but microscopically its groundmass is seen to have an ophitic texture and to consist of fine-grained labradorite and augite, with accessory magnetite. It is therefore best classed as a diabase. The degree of alteration is moderate, the secondary minerals being uralite, sericite, and barkevikite.

CAMPTONITE.

Of far more restricted occurrence are certain basic dikes of a camptonitic nature that cut the alkaline syenites of Salem Neck. They are composed of dense black rocks with very small phenocrysts of a sodic labradorite. The groundmass is essentially labradorite-andesine, barkevikite, and diopside, with accessory biotite, magnetite, and titanite. The texture is slightly ophitic. The hornblende and biotite occur around the diopside and appear to have been derived, at least in part, from its alteration. The rocks have the mineral composition of camptonite, but, as recognized by Washington,[2] are texturally unlike typical camptonite, for they have no phenocrysts of mafic minerals. Comparison of their analysis with the average analysis of camptonite calculated by Daly (see p. 98) shows that these rocks somewhat resemble average camptonite, notably in their high alumina and soda. They are, however, somewhat higher than the average camptonite in silica and are notably higher in magnesia. They resemble the contact-metamorphosed and recrystallized diabases, but their texture is only slightly ophitic. Their high percentages of silica and magnesia show, however, that they have at least chemical similarities to the olivine diabases. If these rocks are composed of contact-metamorphosed olivine-bearing diabase, they must have been metamorphosed before they had cooled to any great

[1] See Washington, H. S., Jour. Geology, vol. 7, p. 290, 1899, for description of 18-foot Pigeon Cove dike north of Rockport, now being studied in detail by C. H. Warren.

[2] Idem, pp. 284–287.

extent. It seems best, therefore, to class them provisionally as camptonite.

On the Beverly-Manchester shore a very few dikes of dark-gray porphyritic rocks cut the syenites and are associated with the vogesitic dikes. The groundmass of the dike rocks is fine grained and is composed essentially of oligoclase-andesine and augite with barkevikite, magnetite, and minor accessories. The phenocrysts are of augite and also of plagioclase feldspar. The alteration is considerable and large amounts of a secondary green hornblende and brown biotite are present, and also chlorite, epidote, calcite, and sericite. These rocks are also camptonitic, although the feldspar is more alkaline than that of typical camptonites. They are transitional between the more mafic camptonites and the more mafic vogesites or camptonitic vogesites.

The following analyses show the composition of camptonite and of certain diabase dikes:

Analyses of diabases and camptonites and average composition of similar rocks.

	1	2	3	4	5
SiO_2	47.12	46.59	40.70	50.12	50.10
Al_2O_3	14.43	17.55	16.02	15.68	14.43
Fe_2O_3	3.33	1.68	5.43	4.55	5.06
FeO	11.71	10.46	7.84	6.73	6.31
MgO	6.05	7.76	5.43	5.85	7.32
CaO	9.63	10.64	9.36	8.80	9.53
Na_2O	2.58	3.31	3.23	2.95	2.75
K_2O	1.11	.72	1.76	1.38	.73
H_2O+	.34	.07	2.62	1.93	2.00
H_2O-	.28	.10			
CO_2			2.97		
TiO_2	3.27	1.41	3.86	1.41	1.25
P_2O_5			.62	.37	.27
MnO			.16	.23	.25
	99.85	100.29	100.00	100.00	100.00
Specific gravity	3.072	3.047			

1. Diabase, Rockport, Cape Ann, H. S. Washington, analyst. Jour. Geology, vol. 7, p. 289, 1899.
2. Camptonite (?), Salem Neck, H. S. Washington, analyst. Jour. Geology, vol. 7, p. 285, 1899.
3. Average camptonite, Daly, R. A., Am. Acad. Arts and Sci. Proc., vol. 45, p. 233, 1910.
4. Average diabase, Daly, R. A., idem, p. 224.
5. Average olivine diabase, Daly, R. A., idem.

VOGESITE.

A few very fine grained dark-gray to black dike rocks have a shiny appearance due to the cleavage faces of small biotites and hornblendes. They are usually porphyritic with phenocrysts of oligoclase (about $Ab_{85}An_{15}$), augite, and more rarely hornblende, although the oligoclase phenocrysts include small flakes of hornblende and biotite. In the groundmass the feldspar ranges from andesine to albite-oligoclase; orthoclase is doubtless present and in some dikes possibly nephelite. The other minerals of the groundmass, whose texture is usually irregular although in places highly ophitic, are augite, pale-green diopside, brown hornblende (barkevikite?), large

amounts of presumably secondary green amphibole, and accessory magnetite and apatite. The dike rocks are moderately altered, and the secondary minerals (besides the green amphibole) are biotite, chlorite, epidote, calcite, and magnetite. The rocks resemble vogesites, but they are really intermediate between vogesites and camptonites, for the feldspar is more calcic than that of typical vogesites. Washington [1] describes and classifies as vogesites similar dike rocks whose feldspar is more alkaline and which are therefore more nearly typical vogesites. He notes also the occurrence of apparently primary quartz in these rocks.

KERSANTITE.

A few dikes similar to the mafic or camptonitic vogesites have a brown biotite as their chief mafic constituent, although they contain considerable augite both as phenocrysts and in the groundmass. They are classed, therefore, in the minette-kersantite series of Rosenbusch, and, as the feldspar is oligoclase (about $Ab_{85}An_{15}$), they are kersantites.

MINETTE.

A large number of dikes similar to the kersantites have a prevailing alkaline feldspar and are therefore best classed as minettes. The prevailing type is a glistening dark-gray to black porphyry, with thin tabular phenocrysts of feldspar. The phenocrysts are greatly altered but are probably oligoclase (about $Ab_{85}An_{15}$). The groundmass consists of a fine irregular aggregate of albite, albite-oligoclase, orthoclase, brown biotite, and a greenish-brown presumably soda-rich amphibole. The accessory minerals are augite, magnetite, and apatite. The alteration is moderate, and the secondary minerals include uralite, chlorite, and sericite, although it is possible that some of the biotite and amphibole are secondary after augite.

Other dike rocks, usually lighter colored than those just described and carrying a more alkaline predominating feldspar, are also classed as minettes. They are composed of fine-grained irregular aggregates of feldspar, brown biotite, yellowish-green hornblende, and a grass-green pyroxene, probably aegirite or aegirite-augite. Their feldspar is of great variety and includes albite, oligoclase, microcline, and microperthite. These dikes commonly contain numerous small rounded masses of dark minerals, chiefly biotite and hornblende. On account of their irregular texture, their varying composition (shown chiefly in the feldspar), and their masses of biotite and hornblende they resemble certain xenoliths in the contact shatter breccias of the alkaline batholiths that are apparently the result of the partial

[1] Op. cit., p. 287.

assimilation of gabbro-diorite or diabase xenoliths by the alkaline syenites.

"AMPHIBOLE FOURCHITE."

Another mafic dike rock which contains about 20 per cent of analcite was found in 1911 by MacKenzie.[1] As described by him the dike is situated on the West Manchester shore on the west side of the point projecting toward Chubb Island, almost 100 yards north from the end of the point, and is exposed only while the tide is below half ebb. It is 30 inches wide and strikes N. 45° E. The dike rock is nearly black and very fine grained and on microscopic examination is seen to consist of almost 30 per cent of light yellow-brown presumably soda-rich amphibole in slender prisms; 20 per cent of pink augite in small prisms, many of which are rimmed with hornblende; 20 per cent of magnetite; and 10 per cent of lath-shaped crystals and anhedral grains of oligoclase (about $Ab_{80}An_{20}$)—all in a groundmass of analcite, some of it in rounded grains that have a faint anomalous birefringence which forms about 20 per cent of the rock. Apatite and fluorite are accessory. The alteration is very slight, the secondary minerals being calcite, chlorite, and probably zeolites. As the rock contains predominating mafic minerals in an analcite groundmass it belongs to the monchiquite family, and as it contains no olivine it is best classed as a fourchite, and, as hornblende is the chief mafic mineral, as amphibole fourchite. It differs, however, in many ways from the type described by Williams.[2]

DIABASE AND GABBRO OF NAHANT.

At Nahant, in the old Cambrian sediments, there are dikes and sheets of diabase porphyry. In the central part of Big Nahant the diabase is coarse grained and loses its typical ophitic texture and thus becomes a true gabbro but one very different from the gabbro and gabbro-diorite of the Salem type. The gabbro is cut by irregular apophyses of a felsic differentiate which is virtually a quartz syenite or nordmarkite, very poor in mafic constituents, its chief feldspar being microperthite. It is impossible to correlate the rocks at Nahant with either the subalkaline or alkaline irruptives (see pp. 31–33), for they occur only on what are virtually three islands, tied together and to the mainland by tombolos or tie bars. On account of the syenitic character of the felsic differentiate, with its microperthite feldspar, the rocks at Nahant are correlated in a general way with the alkaline irruptives. However, their altered character suggests that they are older.

[1] MacKenzie, J. D., manuscript thesis, Massachusetts Inst. Tech., p. 49, 1911.
[2] Williams, J. F., Arkansas Geol. Survey, vol. 2, p. 110, 1890.

The diabase and gabbro are almost identical in their mineral and probably in their chemical composition. For comparison with the other rocks of the area the analysis of the gabbro is given below.

Analysis of gabbro at Nahant.[1]

SiO_2	43.73
Al_2O_3	20.17
Fe_2O_3	4.32
FeO	6.93
MgO	3.91
CaO	10.99
Na_2O	2.42
K_2O	1.45
H_2O+	1.02
H_2O-	.08
TiO_2	4.23
P_2O_5	.15
MnO	None.
	99.40
Specific gravity	3.058

FELSIC DIKES.

The felsic dikes fall into two series—one characterized by a large amount of quartz and related to the granites, the quartz porphyry-paisanite series; and the other with very little or no quartz and related to the syenites, the sölvsbergite-tinguaite series.

QUARTZ PORPHYRY AND PAISANITE.

Large dikes of quartz porphyry occur at the Salem "trap rock" quarry and on the west shore of Marblehead, cutting both the Salem gabbro-diorite and the intrusive Quincy granite apophyses.

These dikes are flesh-colored, with an aphanitic groundmass and small phenocrysts (1 to 3 millimeters in dimensions) of euhedral quartz and white-weathering feldspar. The phenocrysts are surrounded by a narrow zone which is denser and darker than the rest of the groundmass and is seen under the microscope to be spherulitic.

The phenocrysts are quartz and microperthite, the latter consisting of a very fine and rather irregular intergrowth of orthoclase and albite and a few crystals of albite. The essentials of the groundmass are merely alkaline feldspar and quartz. They form spherulites and are also intergrown micrographically. The spherulites surround the phenocrysts of both quartz and feldspar and are also disseminated through the dense microcryptocrystalline groundmass. Near the center they are composed largely of feldspar and fine-grained microperthite, but their outer portions consist of fine micrographic intergrowths of quartz and feldspar. Between the spherulites are irregular grains of quartz, micrographic intergrowths of quartz and feldspar, and microperthite. The accessories, which are not over 1

[1] H. S. Washington, analyst. Jour. Geology, vol. 7, p. 63, 1899.

per cent in amount, are magnetite, titanite, and a blue amphibole (glaucophane or glaucophane-riebeckite similar to that in the paisanite described by Washington [1]) that occurs in very small needles, 0.01 millimeter long. The occurrence of this amphibole in both the salic quartz porphyries and in paisanites and the structural similarity of the two rocks indicate that the two are magmatically related. In fact, a transitional type is known.

This transitional type occurs in an 8-foot dike, striking about N. 50° W., that cuts the alkaline granite on the east shore of Hospital Point, Beverly. The rock is similar in megascopic appearance to the spherulitic quartz porphyry. Near the border of the dike it is much darker than at the center, the difference being more pronounced on the weathered than on the fresh surface. Its mineral composition is identical with that of the quartz porphyry, although near the margins it is somewhat richer in dark minerals. In texture it is transitional between the spherulitic quartz porphyry and the fine-grained paisanite porphyry from Magnolia described by Washington.[2] Spherulites occur, especially around the feldspar phenocrysts, but the rest of the groundmass is merely very fine grained and identical in texture with the paisanite.

Paisanite is typically developed in a dike on Magnolia Point (east of the special area) and has been described and analyzed by Washington.[3]

Analysis of paisanite.

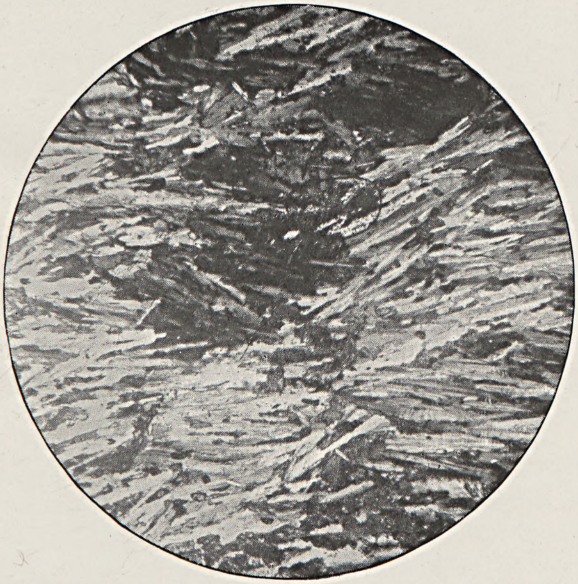
SiO_2	76.49
Al_2O_3	11.89
Fe_2O_3	1.16
FeO	1.56
MgO	Trace.
CaO	.14
Na_2O	4.03
K_2O	5.00
H_2O+	.38
H_2O-	.12
TiO_2	Trace.
MnO	Trace.
	100.77
Specific gravity	2.650

SÖLVSBERGITE AND TINGUAITE.

The sölvsbergites and tinguaites have been described by Washington [4] and Eakle,[5] but some additional information is given here, especially a description of an analcite tinguaite.

[1] Washington, H. S., Jour. Geology, vol. 7, pp. 112–113, 1899.
[2] Idem, pp. 111–114.
[3] Idem, p. 113.
[4] Washington, H. S., Sölvsbergite and tinguaite from Essex County, Mass.: Am. Jour. Sci., 4th ser., vol. 6, pp. 176–187, 1898. Also, Jour. Geology, vol. 7, pp. 114–121, 1899.
[5] Eakle, A. S., A biotite-tinguaite dike from Manchester by the Sea, Essex County, Mass.: Am. Jour. Sci., 4th ser., vol. 6, pp. 489–492, 1898.

A. PHOTOMICROGRAPH OF CONTACT-METAMORPHOSED DIABASE (XENOLITH IN PULASKITE), SHOWING ALTERATION OF AUGITE TO BARKEVIKITE.



B. PHOTOMICROGRAPH OF SÖLVSBERGITE, SHOWING TRACHYTIC TEXTURE.

Sölvsbergite.—As may be seen from Washington's description of the sölvsbergites, they have several minor variations which have given rise to different types which Washington describes separately. They are all gray to dark-gray very fine grained to aphanitic rocks, with a few small phenocrysts of alkaline feldspar. A variety from Salem Neck has a bright silky luster when broken parallel to the grain. An altered sölvsbergite dike from the vicinity of Gale Point, Manchester, is greenish gray.

The sölvsbergite of Salem Neck, which is exposed on the shore of Winter Island north of the Plummer Reform School, consists essentially of albite-oligoclase ($Ab_{90}An_{10}$) and microperthite, a little aegirite, and a greenish-brown hornblende. The accessories are biotite, titanite, and magnetite, the latter in insignificant amount. The sölvsbergite is nonporphyritic, and the texture of the groundmass is extremely trachytic. The feldspars average 1 by 0.04 millimeter and lie nearly parallel. Some of them are bent into an S curve and are interlaced and resemble coarse hay strewn with the blades in one general direction. (See Pl. VI, *B*.) This trachytic texture, although not so pronounced, is characteristic of the sölvsbergites of the Christiania region.

Another sölvsbergite dike, 6 feet wide and cut by diabase with phenocrysts of tabular feldspar, occurs on the Beverly shore south of Prides Crossing. It is porphyritic, and the tabular microperthite feldspars of its groundmass have a parallel to subparallel arrangement. The essential mafic minerals are aegirite and a light yellowish-brown biotite with a very strong absorption. The accessories are nephelite and apatite. The presence of nephelite shows the relation of this rock to the tinguaites. Of all those described by Washington, it is most closely related to the sölvsbergite of Coney Island.

On the Manchester shore, one-fourth mile east of Gale Point, is a complex of dikes, two of which are sölvsbergites. The older dike, which is 3 to 5 feet wide and strikes about N. 65° E., is composed of albite and orthoclase not intergrown. The essential mafic mineral is a brownish-green amphibole. The accessories are diopside, yellow-brown biotite, glaucophane in very fine needles, and magnetite. It resembles the sölvsbergite from East Gloucester.[1] The younger dike, which is 1 foot wide and strikes about N. 55° W., is cut by a diabase with tabular feldspar phenocrysts and is badly altered. It has a greenish color and a somewhat greasy luster, and therefore, although it does not contain recognizable nephelite, it resembles the biotite tinguaite described by Eakle,[2] which occurs one-fourth mile to the west. It consists chiefly of tabular alkaline feldspars, with diverse to subparallel arrangement, with phenocrysts of albite and horn-

[1] Shaler, N. S., Jour. Geology, vol. 7, p. 116 (dike No. 55), 1899.
[2] Eakle, A. S., op. cit., p. 489.

blende (?) in stout prisms, which are now entirely converted to chlorite. This rock resembles most closely the sölvsbergite of Pigeon Cove.[1]

East of West Beach, Beverly, a 4-foot sölvsbergite dike contains small "inclusions" of a black basic porphyry an inch in diameter, which consist of augite and lath-shaped labradorite with ophitic texture and resemble an altered diabase with phenocrysts of labradorite. The alteration is similar to that described under the contact-metamorphosed diabase. The chief secondary mineral is here a greenish-brown hornblende, and the altered labradorite phenocrysts are penetrated and replaced by a clear alkaline feldspar. The main part of the dike is a normal sölvsbergite, with microperthite as the chief feldspar in lath-shaped crystals in diverse to radial arrangement. The principal mafic mineral is a dark-green biotite. A pale-green diopside and small hornblende needles are accessory. The basic "inclusions" can hardly be segregations, although their occurrence in the dike shows their close relation to the normal dike rock. Rather they are cognate xenoliths,[2] probably of intratelluric origin. They are important in showing the genetic relation of the diabase and other mafic dikes to the felsic dikes.

Three published analyses of the sölvsbergite are given below, with the analysis of the average sölvsbergite for comparison.

Analyses of sölvsbergites and average composition of sölvsbergite.

	1	2	3	4
SiO_2	64.28	61.05	60.60	62.16
Al_2O_3	15.97	18.81	18.28	17.58
Fe_2O_3	2.91	2.02	2.85	3.05
FeO	3.18	3.06	2.67	1.80
MgO	.03	.42	.52	.48
CaO	.85	1.30	.99	1.11
Na_2O	7.28	6.56	6.66	7.30
K_2O	5.07	6.02	5.73	4.95
H_2O	.20	.78	.69	1.04
TiO_2	.50	.34	.71	.31
BaO	None.	None.	....	....
P_2O_5	.08	....	.15	.04
MnO	Trace.	Trace.	....	.18
	100.33	100.04	99.85	100.00
Specific gravity	2.703	2.655	....	....

1. Sölvsbergite, dike 184, Andrews Point, Cape Ann, H. S. Washington, analyst. Am. Jour. Sci., 4th ser., vol. 6, p. 178, 1898.
2. Sölvsbergite dike, Coney Island, Salem Harbor, H. S. Washington, analyst. Jour. Geology, vol. 7, p. 118, 1899.
3. Sölvsbergite ("bostonitic alkali syenite porphyry"), Coney Island, M. Dittrich, analyst. Rosenbusch, H., Elemente der Gesteinslehre, p. 199, No. 3, 1898.
4. Average composition of sölvsbergite. Daly, R. A., Am. Acad. Arts and Sci. Proc., vol. 45, p. 253, 1910.

Tinguaite.—Three tinguaite dikes in Essex County have been discovered by Sears. Two are biotite tinguaites, one of them a 6-inch dike at Gale Point, Manchester, described by Eakle,[3] and the other a

[1] Shaler, N. S., op. cit., p. 115 (dike No. 115).
[2] Harker, Alfred, The natural history of igneous rocks, p. 348, 1909.
[3] Eakle, A. S., op. cit., pp. 489–499, 1898.

dike near Squam Light, in Annisquam, described by Washington.[1] The biotite tinguaites are greenish-gray dense rocks, composed of alkaline feldspar, nephelite, and aegirite, with more or less accessory biotite. Other accessory minerals are relatively unimportant.

Washington describes also an analcite tinguaite from Pickard Point, Manchester.[2] He sums up his description as follows:[3] "It is aphanitic and olive-green, with only rare phenocrysts of feldspar in a groundmass of aegirite needles, alkali feldspar, nephelite, and analcite. The perfect freshness of the rock, as well as theoretical considerations, lead to the conclusion that the analcite is primary." Since Washington wrote further evidence has been obtained as to the primary nature of analcite in igneous rocks.[4] The writer has found another analcite rock which, although different from any analcite tinguaite yet described, is probably best classed provisionally as an analcite tinguaite. It forms a dike about 16 feet wide, which has a strike of N. 30° E. and cuts the syenite on the west shore of Manchester Harbor, one-fourth mile northeast of Chubb Island.

The tinguaite is a light-gray, finely crystalline, almost equigranular rock, consisting of white to pinkish, small tabular feldspars and a colorless mineral, with a somewhat greasy appearance, shown on microscopic examination to be analcite. Biotite, occurring in a few small flakes, is the only recognizable accessory mineral. The rock is darker and finer grained near the margins of the dike.

The essential minerals are alkaline feldspar, analcite, and aegirite, the analcite being nearly as abundant as the feldspar. The accessories are small in amount and consist chiefly of biotite. The rock is fresh, only the analcite having undergone alteration to any significant extent.

The feldspar occurs in narrow tabular crystals, twinned after the Carlsbad law and in diverse arrangement. It is alkaline and shows the wavy moire[5] extinction characteristic of anorthoclase. On examination with high powers, however, it is shown to be a very fine and irregular microperthitic intergrowth, probably of albite or anorthoclase and orthoclase. Orthoclase forms a rim around many feldspar crystals and exceptionally occurs as irregular grains.

The analcite is interstitial to the feldspars and resembles a glassy groundmass. It occurs sparingly also in rounded larger phenocryst-like grains, which have a very faint anomalous birefringence. It has

[1] Washington, H. S., Jour. Geology, vol. 7, pp. 119–120, 1899.

[2] Washington, H. S., Am. Jour. Sci., 4th ser., vol. 6, pp. 182–187, 1898.

[3] Washington, H. S., Jour. Geology, vol. 7, p. 119, 1899.

[4] Evans, J. W., A monchiquite from Mount Girnas: Geol. Soc. London Quart. Jour., vol. 57, pp. 38–53, 1901. Ogilvie, I. H., An analcite-bearing camptonite from New Mexico: Jour. Geology, vol. 10, pp. 500–507, 1902. Daly, R. A., Geology of the North American Cordillera at the forty-ninth parallel: Canadian Geol. Survey Mem. 38, pp. 412–416, 1913. MacKenzie, J. D., The Crowsnest volcanics: Canada Geol. Survey Mus. Bull. 4, pp. 19–28, 1914.

[5] Weed, W. H., and Pirsson, L. V., Am. Jour. Sci., 4th ser., vol. 2, p. 196, 1896.

altered to zeolites (?), which occur as dusty clouds that are brightly doubly refracting.

Aegirite occurs in irregular prisms, not typically in needles, although it does occur in some very small needles. It corresponds with the aegirite described by Washington in the analcite tinguaite from Pickard Point.

Biotite, with a yellowish-green to olive-green to black pleochroism, the absorption being very strong, occurs in small shreds. No nephelite was seen, and accessories such as zircon and sodalite do not occur.

No chemical analysis has yet been made of the rock, but the mode has been determined by the Rosiwal method.

Modes of analcite tinguaites.

1		2	
Alkali feldspar	43	Aegirite	10.2
Orthoclase	20	Pyroxene	3.3
Albite	23	Orthoclase	17.3
Analcite	40	Albite	20.9
Aegirite	15	Nephelite	10.9
Biotite and magnetite	2	Analcite	37.4

1. West Manchester.
2. Pickard Point. Washington, H. S., Am. Jour. Sci., 4th ser., vol. 6, p. 186, 1898.

The rock described above is unique in that it contains no nephelite. It is, however, closely related to the analcite tinguaite from Pickard Point and doubtless to the amphibole fourchite, found by MacKenzie[1] 500 feet west of it.

The following analyses of the tinguaites have been published:

Analyses of tinguaites.

	1	2
SiO_2	56.75	60.05
Al_2O_3	20.69	19.97
Fe_2O_3	3.52	4.32
FeO	.59	1.04
MgO	.11	.23
CaO	.37	.91
Na_2O	11.45	7.69
K_2O	2.90	3.24
H_2O+	3.18	1.26
H_2O-	.04	.15
TiO_2	.30	.11
MnO	Trace.	.79
BaO	None.	....
Cl	.28	.28
SO_3	Trace.	....
	99.92	100.04
Specific gravity	2.474	....

1. Analcite tinguaite, Pickard Point, H. S. Washington, analyst. Am. Jour. Sci., 4th ser., vol. 6, p. 185, 1898.
2. Biotite tinguaite, Gale Point, A. S. Eakle, analyst. Am. Jour. Sci., 4th ser., vol. 6, p. 491, 1898.

[1] MacKenzie, J. D., The dikes of West Manchester, Essex County, Mass., manuscript thesis, Massachusetts Inst. Tech., pp. 49–54, 1911.

STRUCTURAL RELATIONS OF DIKE ROCKS.

The dikes, as already indicated (see p. 33), may be subdivided on structural grounds into those that are older than the alkaline batholiths, those that are related to them, and those that are younger. The first, which are chiefly diabases, may be related to the subalkaline batholiths and hence are classed as of post-Ordovician age, and the last, chiefly diabases also, may be correlated with the diabases of the Newark group, of Triassic age. The dikes which are related to the alkaline batholiths are very numerous and of many types. They were injected during and directly following the irruption of the batholith, as is shown by the fact that although they cut the main batholithic rocks, they are cut by aplitic and pegmatitic apophyses, and some have even been broken and pulled apart, apparently by movements in the main batholithic rocks. The structural relations of the dike rocks related to the alkaline batholithic rocks have not been conclusively established, but their sequence of injection appears to be irregular in different parts of the area. It may, however, be given provisionally, from oldest to youngest, as follows:

Olivine diabase porphyries.

Camptonites, vogesites, kersantites, minettes, amphibole fourchite, sölvsbergites, tinguaites, and some diabases with tabular feldspar phenocrysts.

Diabases with tabular feldspar phenocrysts.

Quartz porphyries and paisanites.

Diabase porphyries.

STRUCTURAL RELATIONS OF THE ALKALINE GROUP.

ORDER OF IRRUPTION.

It has been seen that the alkaline group consists of igneous rocks which vary considerably in their composition and in their mode of irruption. All three phases of igneous activity—effusive, injected, and subjacent—are represented. It has also been shown that the Lynn volcanics were accumulated upon an old eroded surface of the subalkaline batholith, and that the dikes, which accompanied the intrusion of the alkaline batholiths, cut the main batholithic rocks. However, with the exception of the porphyritic diabase and the Triassic diabase dikes, all the dikes are cut by younger apophysal phases of the plutonic rocks. It has been formerly supposed that the volcanics were younger than the batholithic rocks. This view has been held by those who have not recognized the presence of two groups of batholithic rocks of greatly different age. The proof collected by the writer, which appears to him to be incontrovertible, shows that the volcanic rocks are older than the alkaline plutonics, although belonging to the same cycle of igneous activity.

This proof may be briefly recapitulated. That there are two granites, the Dedham and the Quincy, greatly different in mineralogic

and chemical nature, is undeniable. The Dedham, which is a granodiorite, has been foliated, secularly weathered to great depths, cut by a great number of dikes, including volcanic dikes, and is unconformably overlain by the Lynn volcanics. The Quincy granite is fresh and unaltered, unfoliated, with but a few large master joints. Along its contact zones it is cut by many dike rocks, but in the central part of its larger stocks or of the batholith dikes are almost unknown. It is not cut by volcanic dikes nor is it overlain unconformably by them. On the other hand, the Quincy granite is intrusive into the Salem gabbro-diorite and the Newburyport quartz diorite of the subalkaline batholith with which it forms extensive contact breccias. It is difficult to explain the occurrence of such extensive shattering unless the rocks into which the alkaline batholith was intruded were completely crystallized and relatively cold. The Lynn volcanics have been folded and broken by an extraordinary number of fissures and joints. They have also been cut by large numbers of diabase dikes, among which are those carrying the peculiar porphyritic tabular feldspars characteristic of one of the dike series of the alkaline eruptives, which is cut by aplites and pegmatites of the normal plutonic rocks. The volcanic rocks are metamorphosed near the Lynn fault, and south of Wenuchus Lake in Lynn they are cut by a small mass of granite which is distinctly of the Quincy type.

The sequence of the three phases of igneous activity in a single cycle has been firmly established by world-wide observations. It has been recently emphasized by Harker.[1] The sequence is (1) the volcanic phase, (2) the plutonic or batholithic phases, and (3) the phase of minor intrusions (dikes and sheets, called by Daly[2] injected rocks) or injected phase. The cycle represented by the alkaline igneous rocks of Essex County is another example of the universality of this normal sequence.

DIFFERENTIATION OF ALKALINE BATHOLITH.

The primary alkaline magma has given rise to a great many types of plutonic rocks. The staple rock is an alkaline granite of the Quincy type. The other varieties are for the greater part confined to the marginal portions of the batholiths. The great diversity of types near the margin of batholithic and laccolithic masses and the comparative uniformity of the central portions have been recognized for a long time and by many geologists.[3] Several explanations proposed for

[1] Harker, Alfred, The natural history of igneous rocks, p. 25, 1909.

[2] Daly, R. A., The classification of igneous intrusive bodies: Jour. Geology, vol. 13, pp. 487-508, 1905.

[3] Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Mont.: U. S. Geol. Survey Bull. 237, 1905; also U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, pp. 563-568, 1900. Harker, Alfred, Carrock Fell: A study in the variation of igneous rock masses: Geol. Soc. London Quart. Jour., vol. 50, pp. 311-337, 1894. Lacroix, Alfred, Le granite des Pyrénées et ses phénomènes de contact: Services carte géol. France Bull. 64, vol. 10, p. 241, 1898.

this marginal diversity may be briefly summarized as magmatic differentiation, acting in accordance with physicochemical laws of solutions and melts; magmatic differentiation acting under the influence of gravity; and contact assimilation, either in the manner suggested by the French geologists or in that first described in detail by Sollas [1] and called by Harker [2] hybridism.

That differentiation was the chief factor in causing the normal variation in the alkaline rocks of Essex County is almost indisputably shown by the transitional nature of the various types and by their great chemical and mineralogic similarity. However, hybridism has been effective in producing certain abnormal rocks (see pp. 117–121), some of which greatly resemble normal differentiates.

ACCOMPANIMENT OF DIKES.

The intrusion of the alkaline batholithic rocks was closely followed and even accompanied by the injection of felsic and mafic dikes. These dikes range from felsic quartz porphyries to camptonites and diabases, yet the end members are connected by transitional or intermediary types. The close relation of the various types to each other and to the batholithic rocks is shown not only by their structural relations but also by their lithologic and chemical similarity. The dikes are confined to the marginal portions of the batholiths and doubtless owe their origin largely to magmatic differentiation in place. They are therefore diaschistic dikes, the felsic and mafic dikes being complementary. However, the close similarity of some types to contact-metamorphosed varieties of other types and the hybrid rocks suggests that the variation in composition of the dikes may be in part explained by contact assimilation, brought about by the process that has been called hybridism.

STRUCTURE OF THE SPECIAL AREA.

The detailed structural geology has been described under the description of formations, and the major structural features have been described in connection with the geology of Essex County. Hence only the most significant features of the structure of the special area need be described here.

FOLDING.

Some time after their eruption the Lynn volcanics and the underlying formations were warped into broad folds which in general trend N. 40° E. In the southwestern part of the area was formed a large anticline, the Saugus-Melrose, and south of it two smaller anticlines, the North Malden and the Maplewood. North of the Lynn

[1] Sollas, W. J., Roy. Irish Acad. Trans., vol. 30, pp. 477–510, 1894.
[2] Harker, Alfred, Jour. Geology, vol. 8, pp. 389–399, 1900.

fault the lack of continuous surface formations makes the anticlinal axes more difficult to determine. However, the Marblehead peninsula is doubtless an anticline. Another, which is apparently the northeastward extension of the Saugus-Melrose anticline, occurs in Peabody and Beverly, the two anticlinal areas being separated by a transverse syncline in North Salem and Danvers.

FAULTING.

The folding is complicated by faulting. It is probable that much of the extensive minor faulting took place during the folding. However, most of the larger faults cut obliquely (approximately N. 80°–90° E.) across the strike of the folds.

NORTH BOUNDARY FAULT.

The southernmost fault is the southern boundary of the igneous rocks. The Cambridge slate of the sedimentary series of the Boston Basin dips steeply to the north against it and is not again exposed. Hence Crosby[1] calls the fault the "north boundary fault" of the Boston Basin. It extends from West Malden across the southern part of the area and can be traced as far east as the village of Franklin Park. Doubtless it extends still farther east, but this part of its course can hardly be even conjectured, although Crosby in 1877 on his map of Boston and vicinity figures it between Nahant and Lynn, evidently basing his conclusion on its general strike farther west. However, as Nahant contains Cambrian metamorphic and irruptive rocks, it seems best to consider the fault as extending south of Nahant. The formations immediately north of the fault are the Lynn volcanics and the Dedham granodiorite, both of which lie unconformably below the sedimentary rocks of the Boston Basin, pebbles of them being found in the Roxbury conglomerate. The north side of the fault is therefore the upthrown. Near the fault plane, which is not actually exposed, the granodiorite and the volcanic rocks have been greatly sheared, and the Cambridge slate (south of the fault) has been contorted and sheared. The fault therefore may be a thrust fault, corresponding to the southern fault of the Boston Basin, which Loughlin[2] believes is a thrust fault.

LYNN FAULT.

From Crystal Lake in Wakefield across Saugus and Lynn the Lynn fault separates the Lynn volcanics and the Dedham granodiorite and Cambrian or pre-Cambrian metamorphic rocks (the old surface rocks upon which the volcanic rocks were accumulated) from

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[1] Personal communication.

[2] Loughlin, G. F., The structural relations between the Quincy granite and the adjacent sedimentary formations: Am. Jour. Sci., 4th ser., vol. 32, pp. 23, 26–27, 1911.

the more deep-seated crystalline rocks, the Newburyport quartz diorite, the Salem gabbro-diorite, and the intrusive alkaline rocks. It doubtless extends farther east between Phillips Point (Swampscott) and Marblehead Neck, both of which areas are virtually rock islands of Dedham granodiorite and Lynn volcanics connected with the mainland by beaches and alluvium only. As the surface rocks occur south of the Lynn fault this side is certainly the downthrown.

The Lynn fault has been located within 1 or 2 feet in many places in Lynn, Saugus, and Wakefield. The rocks on either side are not sheared and are not even greatly altered except near two small intrusions of granite along the fault plane. Neither does there seem to have been any great lateral movement, for if the present relations were brought about by such a movement, the displacement must have been at least 8 miles and very probably 15 miles. This assumption can hardly be made, and as there has been so little shearing of the walls, the writer has decided to consider the Lynn fault a normal one.

WAKEFIELD FAULT.

The fairly large Wakefield fault trends north and south through Wakefield. Along it the sheared rocks have been eroded so that they form a narrow rock valley, through which the railroad runs. The extension of the fault to the south is obscure. The nature of the faulting could not be determined, but as the Lynn volcanic rocks to the east occur in contact with Newburyport quartz diorite to the west, the east side must be the downthrown.

MINOR FAULTING.

A great deal of minor faulting has affected the entire area and especially the southern part. It has caused the extremely irregular contact of the Lynn volcanic rocks with the underlying crystalline rocks in West Saugus, and has taken place also in the North Malden and Maplewood anticlines. Few faults occur in the alkaline granites, but their contact zones have been greatly faulted. As an example of minor faulting the well-known faulted Lincoln dike of Clifton may be cited. This dike, which is a porphyritic diabase related to the alkaline intrusion, is faulted twenty times in 400 yards, but the offset of the faults is only a few feet.

INTRUSION OF ALKALINE IRRUPTIVES.

AGE OF THE INTRUSIONS.

The batholiths and stocks of alkaline granites apparently occur along anticlines. It is probable, therefore, that the folding took place a relatively short time before their intrusion. However, as the numerous dikes which were injected after the irruption of the batho-

liths have been faulted, as was the Lincoln dike, minor faulting must have occurred after the batholiths had crystallized.

There is some evidence that the intrusion of the granite and the major faulting, at least that of the Lynn fault, were virtually contemporaneous. North of the Lynn fault in East Lynn the Salem gabbro-diorite has been sheared, especially near the contacts with the Quincy granite, where hybrid rocks have been developed. The shearing in these rocks is so intense as to suggest that it took place during their formation. The larger granite stocks of the neighborhood show no signs of shearing nor of extensive movement subsequent to solidification.

FAULT INTRUSIONS.

In Lynn, southwest of Wenuchus Lake, and farther west in the Lynn Woods, two very small areas of intrusive granite occur along the actual fault plane. In the western area the granite can be proved to be intrusive only into the "hornfels" and Newburyport quartz diorite, which lie north of the fault; but in the eastern area, the granite is intrusive into both walls, the southern wall being composed of the Lynn volcanic rocks. The intrusive granite, although fine grained and foliated, is of the Quincy type. It is believed that these small intrusions took place along the fault during the faulting in a manner analogous to the fault intrusions at Glen Coe, Scotland,[1] but one can hardly carry the analogy farther, and believe that the downthrown side of the Lynn fault, and indeed the Boston Basin, is a cauldron subsidence. It is also probable that the movement along the fault plane, which was begun during the period of batholithic intrusion, continued after the batholiths had completely crystallized, as the Quincy granite is now found at the same level as the Lynn volcanic rocks, which are presumably the surface equivalents of the Quincy granite.

CONTACT RELATIONS.

SHATTER BRECCIAS.

Geologic position.—It has been shown conclusively that the alkaline batholiths were intruded into the crystallized subalkaline rocks. There are also many reasons for believing that the intrusion took place long after the crystallization of the subalkaline batholith, being separated from it by a long period of erosion and also by one during which a considerable thickness of the Lynn volcanics was accumulated. The periods of erosion may have lasted from Ordovician to early Carboniferous time. During this long hiatus the subalkaline magma must have been crystallized completely. As described, the lower and major part of the batholith consisted of gabbro-diorite. Into

[1] Clough, C. T., Maufe, H. B., and Bailey, E. B., The cauldron subsidence of Glen Coe: Geol. Soc. London Quart. Jour., vol. 65, pp. 611–678, 1909.

this old gabbro-diorite for the greater part the alkaline rocks were intruded, doubtless replacing it in large volume. Also, the alkaline granite cuts the quartz diorite of the subalkaline batholith, the contact being well exposed at the west end of Walden Pond, and apophysal phases of the alkaline granite cut the upper granodiorite zone of the subalkaline batholith. The larger part of the main or molar contacts, however, is with the typical gabbro-diorite, and only along these contacts have the characteristic shatter breccias been developed.

Distribution and character.—The distribution of the shatter breccias is approximately shown on the map. (See Pl. II.) It is of course impossible to draw a sharp line between brecciation and cutting by great numbers of apophysal dikes. This impossibility is emphasized by the little bosses of alkaline plutonic rocks which occur throughout the brecciated areas, suggesting that the main alkaline batholith lies at no very great distance below the present surface. On the map, therefore, the gabbro-diorite is shown as brecciated where it is cut by numerous granitic apophyses, the number of smaller crosses per unit showing roughly the number and extent. The breccias are most extensively developed around the contact of the Peabody stock of Quincy granite, along the axis of small granite stocks extending from Wyoma Lake in North Lynn to Marblehead, and along the shores of Marblehead, South Salem, Salem Neck, and Beverly. They are especially well exposed along the Marblehead shore from Clifton to Devereux. The matrix of the breccias and the apophyses are chiefly granite, but on Naugus Head and Salem Neck and in Beverly they are alkaline syenites. Many similar breccias in other parts of the world have been described by different authors and have been greatly emphasized by Daly[1] and Barrell[2] in explaining the method of igneous intrusion by "stoping."

The breccias are very extensive. Along most contacts they are fully one-fourth mile and in places one-half mile in width. In North Lynn, Swampscott, and South Salem the breccias extend over a much larger area, 8 or 10 square miles, but vary greatly in character.

Neither the thickness nor the dip of the molar contact of the breccia zone can be directly observed in Essex County, for there is not sufficient difference in elevations. However, the great width of the zone suggests that it is correspondingly thick. Even if the moderate dip of 30° is assumed for the molar contact, the zone must in many places be 700 or 800 feet thick. Where the width of the breccia is half a mile or more it is probable that the slope of the molar contact is gentle and that the exposed breccia is underlain at a very moderate depth by the granite. This conclusion is supported by the

[1] Daly, R. A., The mechanics of igneous intrusion: Am. Jour. Sci., 4th ser., vol. 26, pp. 17-50, 1908.

[2] Barrell, Joseph, Geology of the Marysville mining district, Mont.: U. S. Geol. Survey Prof. Paper 57, 1907.

protrusion of numerous small bosses of granite throughout the wide areas of the shatter breccias. An example of such an occurrence is the string of small bosses and stocks between the much larger Peabody and Marblehead stocks of Quincy granite. These bosses doubtless represent a granitic anticlinal axis, and the exposed stocks are merely protuberances of a single large batholith.

The character of the brecciation is known to nearly all geologists, and a much better idea of its appearance may be gained from Plates VII and VIII than from a written description.

Origin.—Although some of the smaller xenoliths appear to be due to the wedging action of apophysal dikes and veins, relatively few of the larger xenoliths seem to have been formed in this manner. (See Pl. VII.) The force most efficient in forming such extremely angular and irregular breccias is apparently the differential expansion of the rocks by the invasion of a molten magma and the consequent comparatively rapid heating of the contact surfaces. Daly[1] has shown that this hypothesis has no theoretic objection in the present knowledge of the physical properties of rocks and magmas, and to this force he attributes the stoping off of large fragments. The character of the shatter breccias as well as the observed blocky contacts of batholiths, such as those described by Barrell[2] at Marysville, Mont., gives the added weight of actual data to the theoretic conclusion. If this hypothesis is correct it must be supposed that the invaded rock was comparatively cold. If this were not true, it would be extremely difficult to explain the extensive shattering in Essex County.

XENOLITHS.

Most inclusions or xenoliths are comparatively unaltered, and their parent rock may be readily determined. The vast majority must be considered not only as "enclaves enallogènes"[3] but as accidental and not cognate[4] xenoliths, for they are fragments of the Salem gabbro-diorite and of the Cambrian and pre-Cambrian (?) metamorphics.

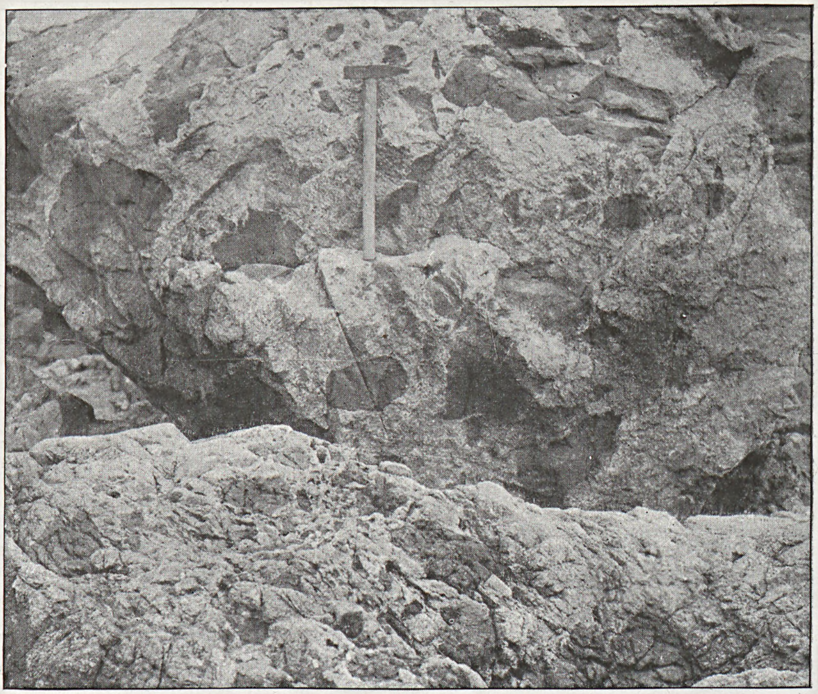
Size and shape.—The xenoliths range in size from minute fragments to large blocks 4 or 5 yards thick and several yards long. However, the largest are comparatively scarce, the greater number being 2 to 10 feet in diameter, although there are of course hosts of smaller ones.

The xenoliths are both angular and rounded, the angular being more numerous. (See Pl. VII, *A* and *B*.) Many of the large xenoliths have evidently broken down into angular fragments. Many small fragments which have been moved some distance from their parent block have preserved their shape so well that one can imagine them fitted together perfectly into a large xenolith. (See Pl. VIII, *A*.)

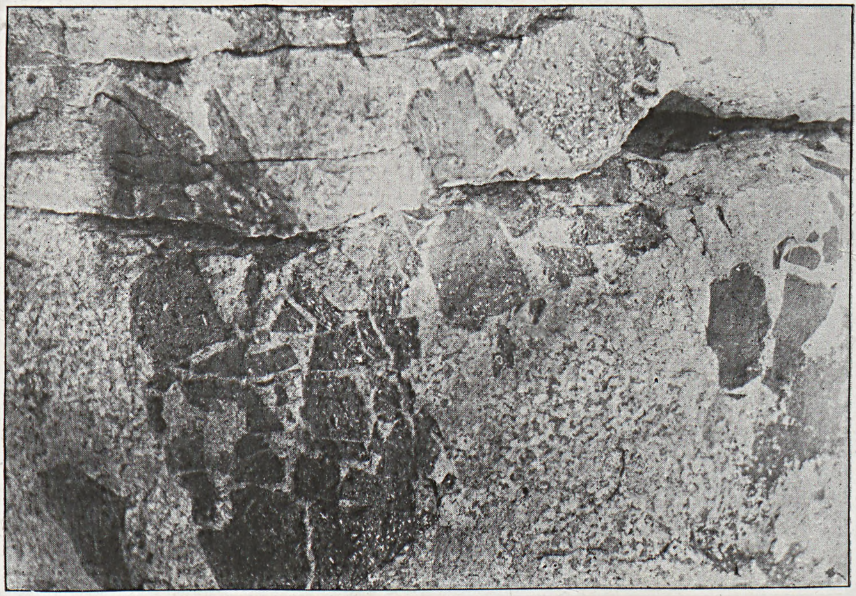
[1] Daly, R. A., Am. Jour. Sci., 4th ser., vol. 25, pp. 22–26, 1908.
[2] Barrell, Joseph, U. S. Geol. Survey Prof. Paper 57, pp. 72–73, pls. 2, 10, 1907.
[4] Lacroix, Alfred, Les enclaves des roches volcaniques: Acad. Mâcon Annales, 2d ser., vol. 10, p. 17, 1893.
[3] Harker, Alfred, The natural history of igneous rocks, pp. 346–347, 1909.

A. CONTACT SHATTER BRECCIA AT CLIFTON, MASS., SHOWING ANGULAR XENOLITHS AND FAULTED LINCOLN DIKE.

B. CONTACT SHATTER BRECCIA SHOWING ANGULAR XENOLITHS.



A. CONTACT SHATTER BRECCIA SHOWING MECHANICAL BREAKING UP OF GABBRO-DIORITE XENOLITHS AND DEVELOPMENT OF PORPHYRITIC CRYSTALS IN THEM.



B. CONTACT SHATTER BRECCIA SHOWING ROUNDED XENOLITHS.

Some of the rounded xenoliths (see Pl. VIII, *B*) have a perfectly sharp contact with the surrounding matrix, which itself may be entirely unchanged. More commonly, however, the rounding looks as if it had been caused by the action of the magma, which has also enriched the matrix near the contacts in the mafic minerals. (See Pl. VIII, *B*.) Some large xenoliths of gabbro-diorite have been converted into several small rounded masses, and yet their original outline may be clearly distinguished by the abnormal amount of dark minerals in the immediate matrix. (See Pl. IX.) Such reaction zones between the gabbro-diorite and the intrusive granite are extremely common, producing intermediary or hybrid types.

"Porphyritic" xenoliths.—Not only has the intrusive granite been enriched in dark minerals, but in the basic xenoliths secondary feldspars and quartz have been developed. Many of these secondary feldspars are euhedral and much larger grained than the primary feldspar of the xenoliths, so that the resulting rock simulates a porphyritic texture. Xenoliths whose margin is "porphyritic" and whose central portion is comparatively unaltered are thus developed. (See Pls. VIII, *A*, and X, *B*.) One or two xenoliths of "porphyritic" texture are rounded, but the others have retained their angular shape.

Gneissic xenoliths.—Another characteristic change noted in the comparatively few xenoliths of Cambrian or pre-Cambrian schist is their conversion to gneisses. So many small dikes and stringers of the granite or syenite have penetrated the schist along foliation planes that the resulting mixture has a striking resemblance to a foliated granitic rock. (See Pl. X, *A*.)

Dikelike xenoliths.—Many of the xenoliths have roughly parallel sides and are much longer than they are wide and hence resemble dikes. Some of these, however, are so completely broken through and dismembered by the matrix that their included nature is undeniable. The larger ones may be due to an infolding of the roof of the alkaline batholith, but most of them are probably due to the shell-like character of the original fragments spalled from the roof. Other xenoliths are actually dikes or basic segregations which were intruded into the granite and subsequently broken, their various portions being separated by subsequent movement of the granite or by later intrusions of granite apophyses.

CONTACT ASSIMILATION AND FORMATION OF HYBRID ROCKS.

There is but little evidence in Essex County that marginal assimilation like that suggested by the French school of geologists[1] was effective, either in preparing the magma chamber or in producing

[1] Lacroix, Alfred, Le granite des Pyrénées et ses phénomènes de contact: Services carte géol. France Bull. 64, vol. 10, 1898.

marginal variations of the plutonic rocks. On the other hand, there is a great deal of evidence that a certain kind of contact assimilation has been active and has produced certain types, very heterogeneous in character, intermediary between the invading plutonics and the country rocks. This assimilation is almost identical with that described by several British petrologists, notably Sollas [1] and Harker.[2] Intermediary types produced by the commingling of two rocks, one or both of them being in a liquid condition, have been called hybrid rocks. Besides the formation of typical hybrid rocks, another feature of the contact action in Essex County is the infiltration of material from the alkaline magma into the relatively cold subalkaline rocks. The nature of this infiltration is similar to that recognized and described by many geologists, in particular by those of the French school.[3]

CONTACT METAMORPHISM OF GRANITES.

EXOMORPHIC METAMORPHISM.

As has been described, the Salem gabbro-diorite in the neighborhood of the intrusive alkaline rocks has been recrystallized. During this recrystallization there was a tendency to form clear untwinned more alkaline plagioclase and to convert the pyroxene into a characteristic common yellowish-green to brownish-green hornblende and brown biotite. Some relatively large biotites, the largest of which are 1 centimeter in diameter, were developed, as in the gabbro-diorite exposed in the railroad cut south of the Salem trap-rock quarry. Most of the gabbro-diorite of the contact zone shows irregular patches of pink weathering feldspar (sodic plagioclase and microperthite), quartz, and recrystallized mafic minerals, chiefly hornblende. The amount of these secondary, partly infiltrated minerals increases until nearly all megascopic traces of the original texture and composition are obliterated. The rock grades into one that contains quartz and alkaline feldspar together with large bladed hornblendes. On microscopic examination the original altered plagioclase (andesine-labradorite about $Ab_{50}An_{50}$) is seen to be surrounded by clear, unaltered secondary feldspar, a more alkaline plagioclase, chiefly oligoclase ($Ab_{85}An_{15}$), orthoclase, and even microperthite. The contact between the primary and secondary feldspar is sharp, although where the surrounding feldspar is plagioclase there is a marked zonal growth in the secondary feldspar with an increase in the percentage of the anorthite molecule near the primary feldspar. Traces of the original altered pyroxene are abundant, but most of it has

[1] Sollas, W. J., On the relation of the granite to the gabbro of Barnavave, Carlingford: Roy. Irish Acad. Trans., vol. 30, pp. 477-510, 1894.

[2] Harker, Alfred, several papers in Geol. Soc. London Quart. Jour. and Geol. Survey Great Britain Mem., summarized in The natural history of igneous rocks, pp. 333-359, 1909.

[3] Barrois, Charles, Soc. géol. Nord Annales, vol. 22, 1894. Lévy, A. M., Services carte géol. France Bull. 36, vol. 5, 1893. Lacroix, Alfred, Services carte géol. France Bull. 64, vol. 10, 1898.

XENOLITH IN CONTACT SHATTER BRECCIA, PARTLY ASSIMILATED AND CONVERTED INTO SMALL ROUNDED MASSES SURROUNDED BY A HYBRID ROCK.

A. CONTACT SHATTER BRECCIA SHOWING XENOLITH OF CAMBRIAN SCHIST INTRUDED BY SYENITE CONVERTING IT INTO A GNEISS AND DEVELOPING "PORPHYRITIC" CRYSTALS IN IT.

B. CONTACT SHATTER BRECCIA SHOWING DEVELOPMENT OF "PORPHYRITIC" ALKALINE FELDSPARS IN A GABBRO-DIORITE XENOLITH, WHICH IN ITS CENTRAL PORTION IS NOT PORPHYRITIC.

gone over to the large yellowish-green hornblendes. Quartz is interstitial. It has a sharp extinction entirely unlike the strained quartz of the Dedham granodiorite or of the Newburyport quartz diorite.

ENDOMORPHIC METAMORPHISM (HYBRIDISM).

Character.—Throughout the contact-breccia zone and notably developed in the breccia of Marblehead there are rocks which are clearly intermediate between granite and gabbro-diorite. They grade into the gabbro-diorite yet also cut it in irregular dikes and are in turn cut by the normal granite apophyses. They are of medium but irregular grain, as a rule finer grained than the granite, and, unlike the granite, are in many places gneissic. They are fairly light colored and consist chiefly of feldspar, quartz, and dark minerals, the dark minerals being much more abundant than in the granite. Here and there they show irregular dark patches which clearly represent remnants of gabbro-diorite.

On microscopic examination the feldspar is seen to be microperthite, some of it in euhedral grains, and an unaltered albite-oligoclase surrounding remnants of an altered labradorite-andesine. Locally microperthite surrounds the remnants. The principal mafic mineral is the yellowish to brownish green common hornblende, which is characteristic of the hybrid rocks. It is very different from the katophorite of the normal Quincy granite. Its pleochroism is $\mathfrak{a}$ = yellowish green, $\mathfrak{b}$ = brownish green, $\mathfrak{c}$ = "muddy" green, and its absorption is not so strong as that of the katophorite. It is negative, with an extinction angle of about 20°. Some of the original pyroxene of the gabbro-diorite remains, but along with biotite it has been largely replaced. Rarely biotite is an essential constituent of typical hybrid rocks. More commonly it is confined to the contact-metamorphosed gabbro-diorite. The accessory minerals of both the granite and the gabbro-diorite (magnetite, zircon, apatite, and titanite) are present.

Formation.—Two localities where typical hybrid rocks are well exposed have been given special study in order to make clear the formation of these rocks. One of these localities is at the eastern end of the elongate stock of Quincy granite in North Lynn, near the Lynn-Swampscott boundary, one-half mile from the ocean; and the other is on the western contact of the Peabody stock of Quincy granite in a railroad cut in Lynnfield, one-half mile east of Montrose station. In North Lynn the country rock is a normal medium-grained gabbro-diorite. It is characteristically altered. The original mafic constituent is chiefly diallagic augite, and the most abundant secondary mafic mineral is biotite. The feldspar has been sericitized. A little secondary feldspar has been developed, and a very small amount of secondary quartz (recognized as secondary by its sharp extinction)

occurs in the interstices of the original grains. The intrusive granite is typical of the apophysal phases of the Quincy granite, being rich in quartz and very poor in mafic minerals. The principal accessories are magnetite, zircon, and titanite. Near the contact of the two types the gabbro-diorite has been recrystallized and a zone, one-sixteenth inch thick, of coarsely recrystallized magnetite lies along the immediate contact. Beyond the magnetite zone are large euhedral yellowish-green common hornblendes, the largest of which are 0.8 centimeter in diameter, that extend for some distance away from the gabbro-diorite, gradually decreasing in number. The interstices of the hornblende and magnetite are filled with quartz and microperthite, together with some albite-oligoclase. The microperthite and quartz increase as the hornblendes decrease until the rock passes gradually into a normal granite. (See Pl. XI.)

This process of formation of hybrid rocks evidently took place on a much larger scale at an earlier stage of the intrusion, for very considerable areas of a similar rock are found. The feldspars of this rock are extremely variable in composition, single individuals ranging from $Ab_{50}An_{50}$ in their central part to $Ab_{85}An_{15}$ at their margins; grains of albite-oligoclase and microperthite occur also. Much of the diallage of the gabbro-diorite remains but appears to be altering directly to coarse-bladed hornblendes of the variety characteristic of hybrid rocks. In some types the hybrid nature of the rock is not so clearly shown, for the texture is more uniform and all the original pyroxene has been converted to hornblende.

At the east end of the 225-foot railroad cut east of Montrose station about 50 feet of a quartz-rich Quincy granite is exposed. West of this exposure is a zone 25 feet wide of a hybrid rock intruded by numerous apophyses of the quartz-rich granite. The rock resembles the granite more closely than most of the hybrid types and shows clearly its relation to it in that it retains the texture of the Quincy granite and contains considerable microperthite. Next is a zone 100 feet wide, where inclusions of gabbro-diorite occur in the hybrid rock, which grows more mafic toward the west end. Both rocks are cut by granitic apophyses and pegmatite. At the west end of the cut is 50 feet of gabbro-diorite, cut chiefly by pegmatite.

In the central breccia zone irregular tongues of granite penetrate the gabbro-diorite and appear to have absorbed mafic constituents from it and to have recrystallized them into euhedral hornblendes and magnetites in the manner already described. (See Pls. XII, XIII.) The border zone of recrystallized magnetite is well shown on Plate XIV. In other places small angular fragments of the gabbro-diorite appear to have been detached from larger inclusions and to have floated off into the granite magma, where they were broken into smaller and smaller fragments, which finally recrystallized into large

DETAIL OF CONTACT BETWEEN GRANITE OF THE PEABODY STOCK OF QUINCY GRANITE AND SALEM GABBRO-DIORITE, SHOWING FORMATION OF A HYBRID ROCK.

DETAIL OF CONTACT BETWEEN GRANITE OF THE PEABODY STOCK OF QUINCY GRANITE AND SALEM GABBRO-DIORITE, SHOWING FORMATION OF A HYBRID ROCK.

euhedral hornblendes or formed patches of basic minerals in the hybrid rock. (See Pl. XV.)

Oddly enough the pegmatite, supposedly rich in gases and cutting both the hybrid rock and the gabbro-diorite, has had apparently little or no effect on the composition of either, although it contains a very few secondary hornblendes.

The process of hybridism described above is similar to that described by Sollas[1] as occurring at the contact of dikes of granophyre intrusive into the gabbro of Barnavave in Carlingford, Ireland. In many respects the processes are virtually identical, as in the altering of xenocrysts of diallage to a "sage-green" hornblende; in the pronounced zonal structure of the plagioclase feldspar with a wide variation in composition and a marginal zone of clear feldspar, commonly orthoclase; and in the occurrence of dark patches in the granophyre which are clearly corroded xenoliths.[2]

Chemistry.—The hybrid rock from the central zone of the Montrose railroad cut has been analyzed and its chemical composition is given as follows:

Analysis of hybrid rock.

[M. F. Connor, analyst.]

SiO_2	64.74
Al_2O_3	15.45
Fe_2O_3	.64
FeO	3.85
MgO	1.47
CaO	4.27
Na_2O	3.71
K_2O	2.48
H_2O-	.10
H_2O+	1.06
TiO_2	1.11
P_2O_5	.10
MnO	.06
BaO	.04
CO_2	.95
S	.02
	100.05

The relations of the hybrid to the granite and to the gabbro-diorite are shown in figure 4. As Harker[3] has pointed out, a true hybrid rock should have a composition exactly intermediate between the two parent rocks, and the various oxide percentages of the hybrid should, therefore, in a variation diagram, lie in straight lines connecting the oxide percentages of the two extremes. The accompanying diagram (fig. 4) shows that this criterion is nearly true for

[1] Sollas, W. J., Roy. Irish Acad. Trans., vol. 30, pp. 477-510, 1894.

[2] Idem, pp. 494-495.

[3] Harker, Alfred, Jour. Geology, vol. 8, pp. 389-399, 1900.

MgO, TiO_2, Fe_2O_3, Na_2O, CaO, and FeO. Al_2O_3 is, however, somewhat too high and K_2O is considerably too low. Harker[1] himself recognizes, however, that though his statement as to the composition of hybrid rocks is necessarily true of the rocks in bulk, "it does not always

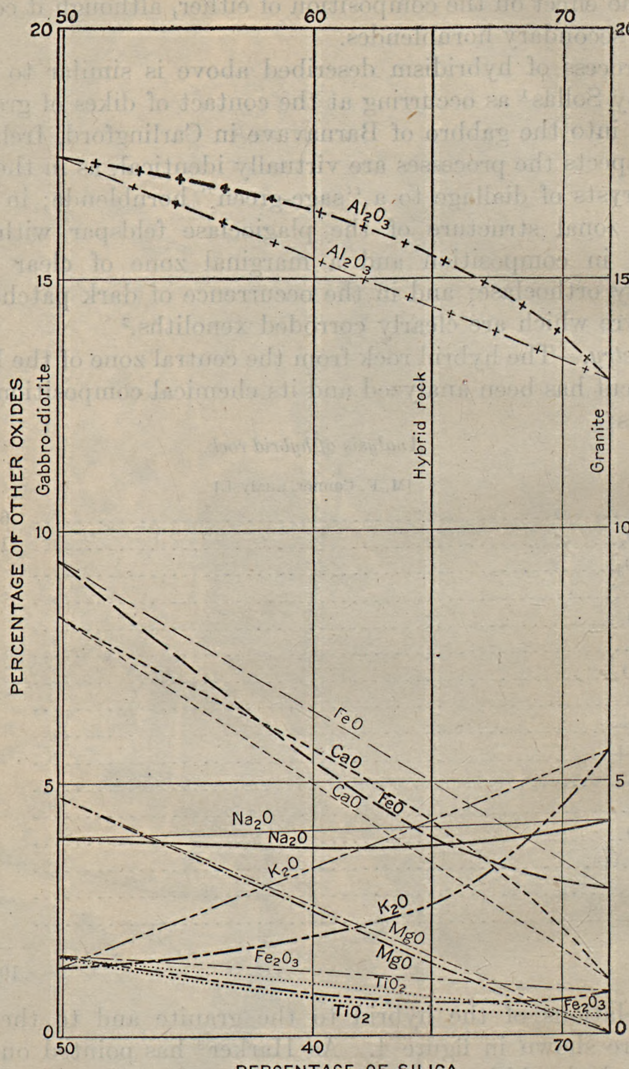


FIGURE 4.—Diagram showing variation of rock hybrid between granite and gabbro-diorite and its relation to the parent rocks.

hold good of every specimen, for admixture may be complicated by unequal diffusion of the different constituents." This unequal diffusion doubtless explains part of the variation from the theoretic composition in the hybrid rock from the Montrose railroad cut. It

[1] Harker, Alfred, The natural history of igneous rocks, p. 358, 1909.

DETAIL OF CONTACT BETWEEN GRANITE OF THE PEABODY STOCK OF QUINCY GRANITE AND SALEM GABBRO-DIORITE, SHOWING FORMATION OF A HYBRID ROCK.

DETAIL OF CONTACT BETWEEN GRANITE OF THE PEABODY STOCK OF QUINCY GRANITE AND SALEM GABBRO-DIORITE, SHOWING RIM OF RECRYSTALLIZED MAGNETITE AROUND THE GABBRO-DIORITE AND RECRYSTALLIZED HORNBLENDE IN THE GRANITE.

has been shown, however, that the chief feldspar to form even in the most felsic phases of the hybrid is plagioclase, not orthoclase. This is more clearly shown in the hybrid types of the syenite contacts. Hence, it is probable that potash is not so easily incorporated into the hybrid rock as soda and lime. The hybrid types of the syenite contacts are comparatively richer in potash. However, a large part of it is doubtless contained in the nephelite and biotite, which characterize the rocks contact-metamorphosed by alkaline syenite intrusions.

CONTACT METAMORPHISM OF THE SYENITES.

EXTENT.

The contact action of the syenites has been studied chiefly at Salem Neck. The metamorphism, although not so extensive as that produced by the granite, is relatively greater, for the syenites occur in much smaller masses. The relations and origin of the syenite contacts are perhaps not so clear as those of the granite contacts, chiefly on account of the greater variation of the metamorphosed rocks, That hybridism has taken place to a very great extent is, however. undeniable.

The Salem gabbro-diorite is the chief rock of Salem Neck. It is, however, brecciated throughout by syenite intrusions and is cut by several large dikes of alkaline and nephelite syenites. The Salem gabbro-diorite is here chiefly a gabbro, for even the contact-metamorphosed phase contains only 45.32 per cent of silica,[1] and olivine is present in places as a major accessory mineral.

EXOMORPHIC METAMORPHISM.

The gabbro-diorite has been recrystallized to a fine to medium grained dark-gray rock of fresh unweathered minerals. The feldspar is an andesine-labradorite (about $Ab_{55}An_{45}$), which occurs in clear, faintly twinned, in places euhedral grains. The mafic minerals are principally a pale-green diopside and a yellow-brown biotite. The diopside occurs in small anhedra and the biotite in larger, irregular flakelike grains, many of which include euhedral feldspars. Hornblende, which is scarce, also includes euhedral feldspars. It is a yellowish to olive-green variety, similar to that of the umptekite and of the contact phases of the nephelite syenite. Accessory magnetite, ilmenite, titanite, and apatite are abundant. Some coarse-grained varieties of the gabbro-diorite are more feldspathic than others.

As already stated, most of the gabbro-diorite is less siliceous than the variety described above and has resulted from the recrystallization of a gabbro. The rocks are dark, almost black, of fine

[1] Washington, H. S., Jour. Geology, vol. 7, p. 63, 1899.

to medium grain, and megascopically appear to be entirely recrystallized. The feldspar, chiefly labradorite-andesine ($Ab_{40}An_{60}$ to $Ab_{55}An_{45}$), occurs in clear and in places euhedral grains. The essential dark minerals are pyroxene, which is a nearly colorless augite and occurs in small anhedra, with a few larger grains, and a peculiar brown hornblende. The hornblende is extensively but irregularly developed. It has grown around the feldspars and augite (see Pl. XVI, *A*) and is clearly of later crystallization. A small amount of biotite, with a peculiar pleochroism ranging from brownish orange to deep brownish red, occurs in the same textural relations as the hornblende. In many rocks the original texture and the altered original minerals are preserved, and it is seen that the recrystallized variety is assuredly derived from a gabbro of the Salem type. (See Pl. XVI, *B*.)

The fine-grained recrystallized gabbro is surrounded by wide zones of much more coarsely recrystallized rock of essentially the same mineral composition and texture but with a tendency to be more feldspathic and with a wider range of composition of the plagioclase. This coarse rock also occurs in irregular streaks through the fine-grained gabbro. In the coarsely recrystallized gabbro there have been developed large poikilitic crystals, many of them 2 to 3 centimeters in diameter, of biotite and amphibole,[1] which include plagioclase, feldspars, and large recrystallized grains of augite, some of which include olivines, with an altered rim of serpentine. Many of these crystals are associated with thin veinlets of microperthite, which have worked their way for relatively long distances into the country rock in a manner analogous to that described by Sollas.[2] The poikilitic amphiboles and biotites are identical with those developed in the recrystallized gabbro. The optical properties of the amphibole are $\mathfrak{a}$ = very pale reddish brown, $\mathfrak{b}$ = deep reddish brown, and $\mathfrak{c}$ = greenish brown. The extinction angle $c : \mathfrak{c} = 14°$. The mineral is negative, and the birefringence is high (about 0.040). The amphibole is probably the variety barkevikite.[3] Amphibole and biotite of a similar character are described by Sollas [4] as occurring in the recrystallized and contact-metamorphosed Barnavave gabbro of Carlingford. Some of the "poikilitic" gabbro is very coarse grained and passes into a rock that contains 60 to 70 per cent of feldspar. The feldspars occur in long, tabular, euhedral crystals, not microperthite but plagioclase labradorite-andesine, with a pronounced zonal growth. The mafic minerals are chiefly poikilitic hornblendes and biotites, although small, irregular patches of hornblende and augite occur.

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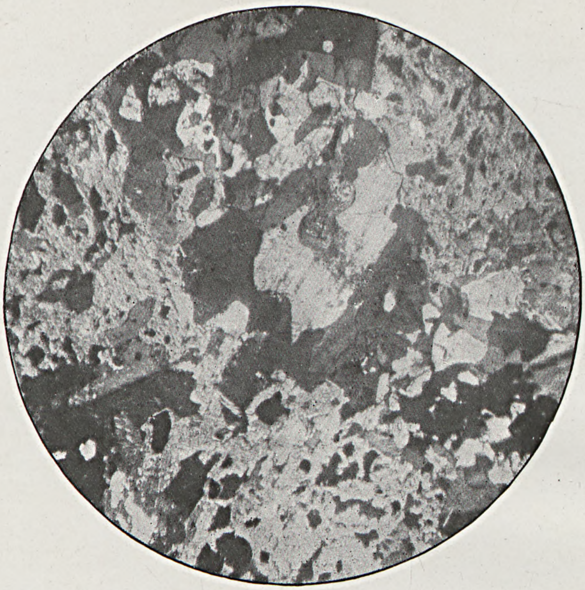
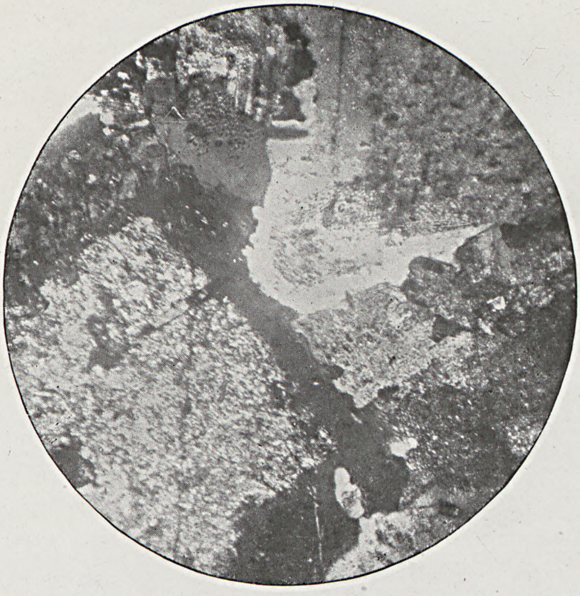
[1] Cf. Grubenmann, U., Poikiloblastiche Struktur, in Die kristallinen Schiefer, pt. 1, p. 80, 1904.
[2] Sollas, W. J., Roy. Irish Acad. Trans., vol. 30, pp. 480–481, 1894.
[3] Washington, H. S., Jour. Geology, vol. 7, p. 56, 1899.
[4] Sollas, W. J., op. cit., pp. 493–495.

DETAIL OF CONTACT BETWEEN GRANITE OF THE PEABODY STOCK OF QUINCY GRANITE AND SALEM GABBRO-DIORITE, SHOWING PATCHES OF DARK MINERALS IN THE HYBRID ROCK AND ALSO EUHEDRAL HORNBLENDE FORMED BY THE RECRYSTALLIZATION OF SMALL FRAGMENTS FROM THE GABBRO-DIORITE.



A. PHOTOMICROGRAPH OF FINE-GRAINED RECRYSTALLIZED GABBRO-DIORITE WITH IRREGULAR AND POIKILITIC TEXTURE.



B. PHOTOMICROGRAPH OF CONTACT-METAMORPHOSED GABBRO-DIORITE, SHOWING CLEAR SECONDARY ALKALINE FELDSPAR AROUND SERICITIZED ANDESINE-LABRADORITE.

The coarse-grained poikilitic olivine-bearing variety is the "hyperitic diorite" or hornblende gabbro of Washington,[1] who gives the following analysis:

Analysis of hornblende gabbro.[2]

SiO_2	45.32
Al_2O_3	18.99
Fe_2O_3	3.78
FeO	9.78
MgO	4.68
CaO	9.19
Na_2O	3.78
K_2O	2.12
H_2O+	.31
H_2O-	.09
TiO_2	1.94
	99.98

ENDOMORPHIC METAMORPHISM.

Types.—Hybrid types, analogous to those developed at the contact of the gabbro-diorite and granite, also occur on Salem Neck. The rocks grade into the gabbro-diorite and are cut by the syenites. They vary a great deal in texture and mineral composition.

Most of the hybrid rocks are medium grained, dark gray, and very commonly have large "phenocrysts" of tabular feldspar. Wherever the rock is apparently in the process of formation it contains irregularly distributed small black patches of fine aggregates of biotite and hornblende. Its chief minerals are plagioclase, orthoclase, microperthite, nephelite, a pale-green diopside, a brownish-green hornblende, brown biotite, and accessories, such as magnetite and titanite, and olivine where the hybrid rock was derived from an olivine-bearing gabbro or olivine diabase. In the more basic varieties the feldspar is largely plagioclase, which has a pronounced zonal growth, with a wide variation in composition. It is, however, chiefly andesine-labradorite. Between the larger crystals of plagioclase, which are recrystallized xenocrysts rather than phenocrysts, small euhedral grains of orthoclase and albite occur. Where the intrusive syenite is nephelite bearing, nephelite occurs in places in the resulting hybrid rock.

The basic hybrid types pass into more siliceous types in which the chief feldspar is microperthite, which in many places occurs as large but irregular crystals that give the rock a porphyritic appearance. Plagioclase and pyroxene are everywhere present but occur with the other minerals in small irregular grains. These siliceous types are also comparatively rich in titanite.

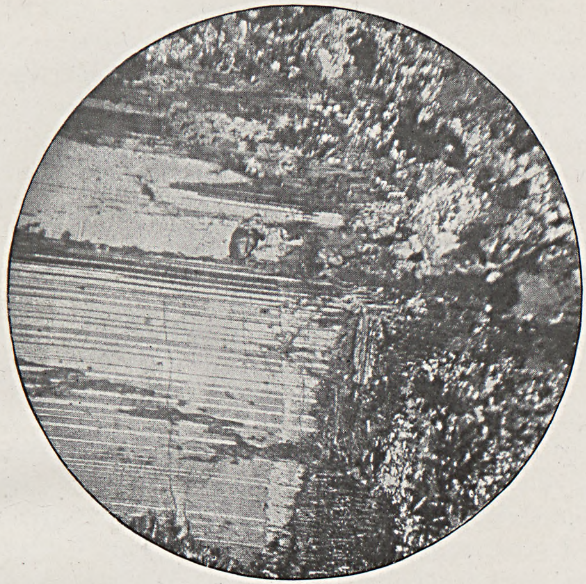
[1] Sollas, W. J., op. cit. pp. 493–495.
[2] Hornblende gabbro, Salem Neck. H. S. Washington, analyst. Jour. Geology, vol. 7, p. 63, 1899.

On a ledge south of Fort Avenue, on Salem Neck, 200 yards north of the pumping station, a typical example of hybridism is seen. The ledge consists of a fine-grained porphyritic diabase, which has been altered and recrystallized by contact metamorphism and cut and brecciated by nephelite syenite. Surrounding many of the diabase xenoliths and extending irregularly into them is a somewhat lighter colored rock, intermediate in appearance between the diabase and the nephelite syenite. This intermediary or hybrid rock also occurs in the nephelite syenite as inclusions, some of which have indefinite outlines and are cut by nephelite syenite apophyses. Traces of the original ophitic texture are seen in the diabase, but the groundmass is now granular and consists largely of greenish-brown hornblende, diopside, and biotite, with a clear untwinned plagioclase. The phenocrysts are labradorite ($Ab_{40}An_{60}$) with a well-developed twinning and are not clouded with decomposition products. Megascopically the rock apparently grows porphyritic near its contacts with the syenite—that is, within 1 or 2 feet of them. This appearance is due, however, to the replacement of the plagioclase phenocrysts by microperthite. (See Pl. XVII, *A*.) The microperthite surrounds the plagioclase and fingers into it, completely replacing it. The resulting "phenocryst," which on account of its relative opaqueness is more prominent megascopically, has a very peculiar, ribbon-like structure. (See Pl. XVII, *B*.)

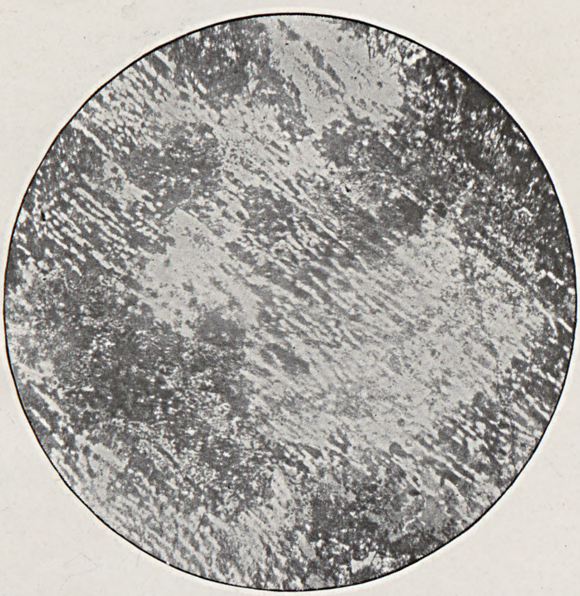
The hybrid rock is dark gray and fine-grained and carries xenocrysts of plagioclase and small round patches of black minerals. Under the microscope it is seen to be composed of plagioclase, which is partly replaced by microperthite, the partial replacement making a pseudomicrographic structure. (See Pl. XVIII, *A*.) The mafic minerals biotite, pyroxene, and hornblende occur in irregular grains, in many places crowded together closely in most irregular fashion. (See Pl. XVIII, *B*.) These aggregations are the patches of black minerals so prominent megascopically. Once in a while large xenocrysts of pink augite occur, which, even if the other features did not clearly indicate the nature of the rock, would show conclusively its hybrid origin.

Essexite.—Comparison of the descriptions of the contact-metamorphosed gabbro and diabase and of the hybrid rock with those of the essexite of Salem Neck given by Rosenbusch[1] and Washington[2] shows that the essexite and the contact-metamorphosed and hybrid rocks have many points in common and that indeed some of their phases are identical. The conclusion is, therefore, that the essexite of Salem Neck is not a differentiate of the alkaline or nephelite syenites but is a contact-metamorphosed gabbro or gabbro-diorite

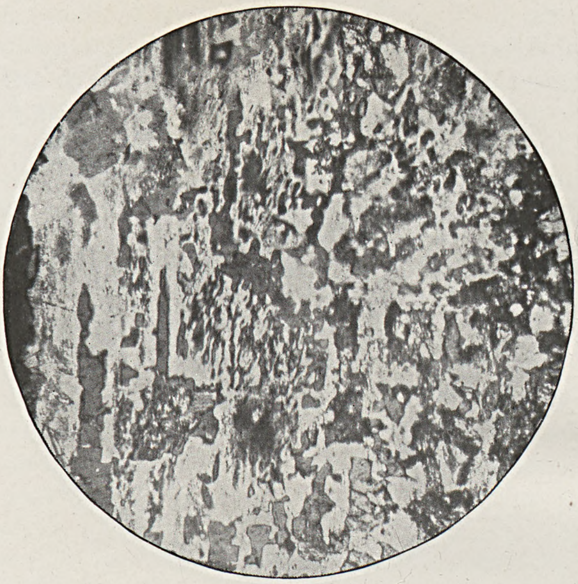
[1] Rosenbusch, H., Mikroskopische Physiographie der Mineralien und Gesteine, pt. 2, p. 398, 1907.
[2] Washington, H. S., Jour. Geology, vol. 7, pp. 53-57, 1898.



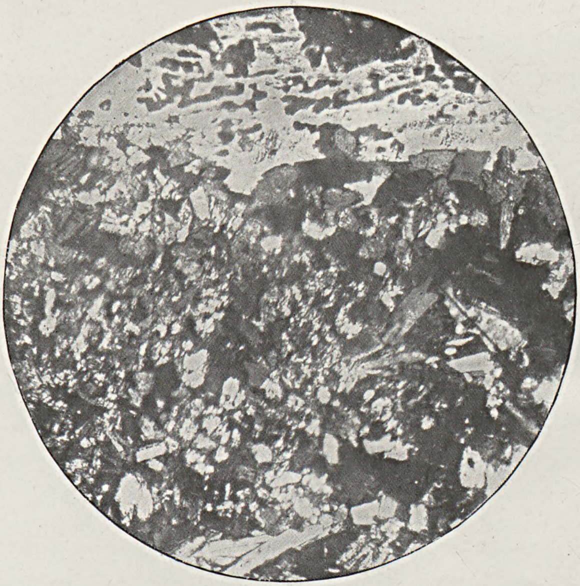
A. PHOTOMICROGRAPH OF CONTACT-METAMORPHOSED OLIVINE DIABASE PORPHYRY, SHOWING PHENOCRYST OF LABRADORITE BEING REPLACED BY MICROPERTHITE.



B. PHOTOMICROGRAPH OF CONTACT-METAMORPHOSED OLIVINE DIABASE PORPHYRY, SHOWING "PHENOCRYST" OF MICROPERTHITE WITH "RIBBON STRUCTURE."



A. PHOTOMICROGRAPH OF HYBRID ROCK, SHOWING "PHENOCRYST" WITH PSEUDOMICROGRAPHIC TEXTURE.



B. PHOTOMICROGRAPH OF HYBRID ROCK, SHOWING "BLACK SPOT" CONSISTING OF AN AGGREGATE OF BIOTITE, HORNBLENDE, AND DIOPSIDE, AND "PHENOCRYST" WITH PSEUDOMICROGRAPHIC TEXTURE.

of the Salem type or in some places a metamorphosed olivine-bearing diabase. The schistose varieties and the more siliceous varieties of essexite, such as those containing microperthite, considerable nephelite, and large fawn-colored augites, are true hybrid rocks. This conclusion may appear somewhat radical to many who are not personally acquainted with the field evidence. However, it may be seen from the descriptions of Rosenbusch and Washington that the essexite of Salem Neck is extremely variable. Washington [1] writes as follows:

They [the essexites] are quite distinct from this [the nephelite syenite], and, as far as I know, few transitional forms into this rock have been seen. [None have been found since except undoubted hybrid rocks.] On the other hand, they grade into the diorites of the neighborhood, so that in this direction it is difficult to draw a hard and fast line.

It has been shown that the Salem gabbro-diorite is a member of the subalkaline batholith, which is much older than the alkaline plutonic rocks. The essexites of Salem Neck undoubtedly grade into the gabbro-diorites; they are brecciated by the syenites; and they occur only in the contact-breccia zone and never as distinct intrusions into the gabbro-diorite. These structural considerations strongly support the conclusion that the essexite is of hybrid origin.

The published analyses of the essexite are given below. Analyses 1 and 2 are of specimens collected by Mr. Sears, presumably from the same outcrop, and therefore do not show wide variation.

Analyses of essexites and composition of average essexite.

	1	2	3	4
SiO_2	46.99	47.94	48.69	48.40
Al_2O_3	17.94	17.44	17.91	16.67
Fe_2O_3	2.56	6.84	3.09	5.31
FeO	7.56	6.51	6.41	6.03
MgO	3.22	2.02	3.06	4.48
CaO	7.85	7.47	7.30	9.05
Na_2O	6.35	5.63	5.95	4.45
K_2O	2.62	2.79	2.56	2.13
H_2O	.65	2.04	.95	.95
TiO_2	2.92	.20	2.71	1.71
P_2O_5	.94	1.04	1.11	.67
MnO	Trace.	....	.15	.15
BaO	None.	....	.08	....
	99.60	99.92	100.02	100.00
Specific gravity	2.919	....	....	....

1. Essexite, Salem Neck. H. S. Washington, analyst. Jour. Geology, vol. 7, p. 57, 1899.
2. Essexite, Salem Neck. M. Dittrich, analyst. Rosenbusch, H., Elemente der Gesteinslehre, Zweite Auflage, p. 177, 1901.
3. Olivine-bearing essexite, Mount Johnson, Quebec, Canada. Also contains NiO+CoO, 0.05 per cent. Adams, F. D., Jour. Geology, vol. 11, p. 215, 1903.
4. Average essexite. Daly, R. A., Am. Acad. Arts and Sci., vol. 45, p. 227, 1910.

It is seen that the essexite of Salem Neck does not differ essentially from the average essexite, or from the essexite of Mount John-

[1] Op. cit., p. 53.

son, which is almost assuredly a normal differentiate of an alkaline magma. A hybrid rock may therefore resemble a "normal" igneous rock.

Diabase-pulaskite.—An interesting example of hybridism occurs about one-fourth mile east of Gale Point, Manchester. A 7-foot dike of diabase containing tabular feldspar phenocrysts is cut along one wall by a 1-foot dike of fine-grained pulaskite. The diabase is also brecciated by the pulaskite, and rounded fragments of it are included in the pulaskite (see p. 103), some of which have been assimilated, thus producing a hybrid rock which now forms the larger part of the 7-foot dike. This hybrid rock is very heterogeneous in character. The larger part is not greatly different from the normal pulaskite but has a much larger percentage of dark minerals. It contains, however, large xenocrysts of augite and altered labradorite, the labradorite being surrounded by a rim of clear microperthite.

CONCLUSION.

Harker, after showing that hybridism is very significant and possibly has a very wide application, sums up[1] by saying that hybridism is merely a disturbing factor in the derivation of igneous rocks by magmatic differentiation. In a sense this is true, although it is possible to imagine a deep-seated hybridism and assimilation on a very large scale, such as Sollas[2] points out, which would be very effective in the formation of new rock types. Hybridism, which takes place at the upper contacts of batholiths, is nearly as limited in its application to the production of new rock types as is the ordinary contact assimilation described by Lacroix and other French geologists. Lacroix has shown that under special conditions contact assimilation is very powerful, and the hybridism shown in Essex County, as well as that described by Sollas and Harker, proves that hybridism may sometimes be most efficient in producing new rock types.

It has also been shown that extensive hybridism is not confined, as stated by Harker, to the interaction of magma and cognate xenoliths, but that it may take place between magma and relatively cold country rock.

The temperature of the invading magma and the character and composition of the country rock are doubtless controlling conditions, as is shown by the fact that although the main Peabody stock of Quincy granite cuts the quartz diorite zone of the subalkaline batholith no hybrid rocks have been developed.

That interpretation of the field and petrographic evidence which has been given serves to clear up what to the "single-minded differentiationist" (to use Sollas's term) would be an almost hopeless puzzle.

[1] Harker, Alfred, The natural history of igneous rocks, pp. 342–343, 1909.
[2] Sollas, W. J., Roy. Irish Acad. Trans., vol. 30, pp. 503–509, 1894.

ANALYSES.

The analyses of rocks from Essex County given in the accompanying table (in pocket) have been taken from the chemical analyses collected and classified by Washington.[1] The analyses are grouped according to the quantitative classification and are numbered as in Washington's tables. Beneath the number is shown the rating of the analysis (A1.I, A3.III, etc.) according to Washington's scheme.[2] In addition to the analysis of the rock and its classification in the quantitative system the table shows the molecular numbers of the constituents in smaller type beneath their percentages. The norms, as calculated by Washington from the analysis by the method which he describes,[3] are also given.

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[1] Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, 1917.
[2] Idem, pp. 24–26.
[3] Idem, pp. 1162–1165.

INDEX.

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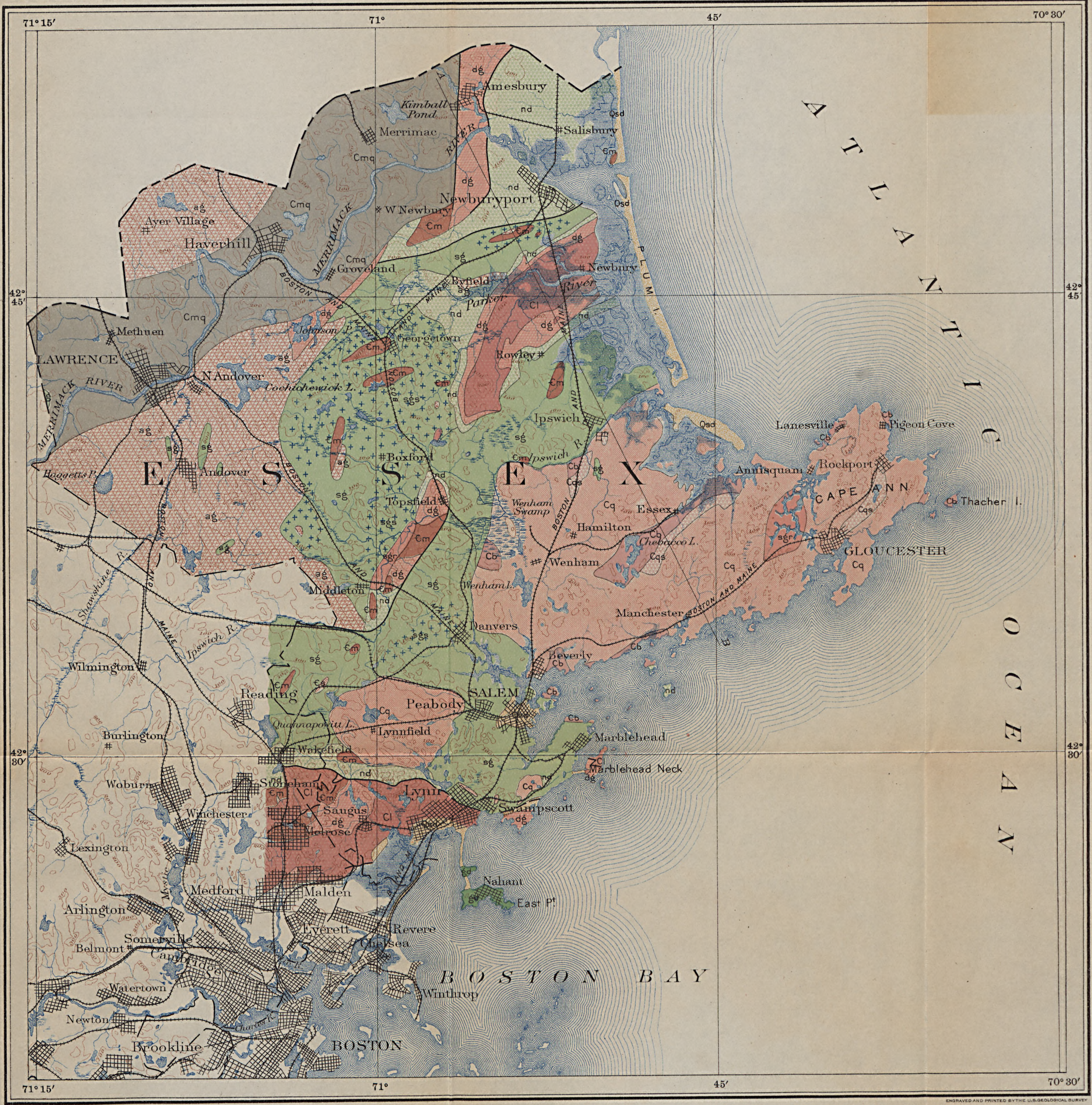


GEOLOGIC RECONNAISSANCE MAP AND STRUCTURE SECTION OF ESSEX COUNTY, MASSACHUSETTS

Base from U. S. Geological Survey topographic map of Massachusetts

Geology by C. H. Clapp

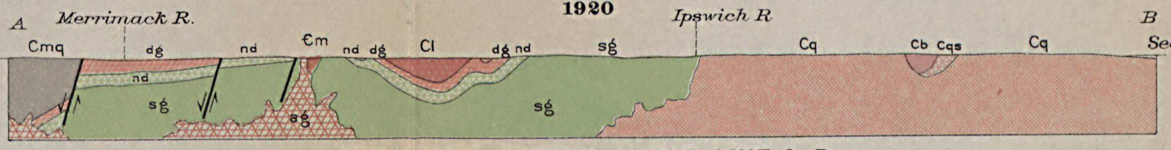
Scale $\frac{1}{250,000}$

0 5 10 15 Miles

0 5 10 15 Kilometers

Contour interval 100 feet.
Datum is mean sea level.

1920



STRUCTURE SECTION ALONG LINE A–B

EXPLANATION

SEDIMENTARY AND METAMORPHIC ROCKS

QUATERNARY
- Qsd — Surficial deposits of Recent and Pleistocene age

CARBONIFEROUS
- Cmq — Merrimack quartzite

CAMBRIAN AND ALGONKIAN (?)
- €s — Serpentine
- €m — Metamorphic rocks

IGNEOUS ROCKS

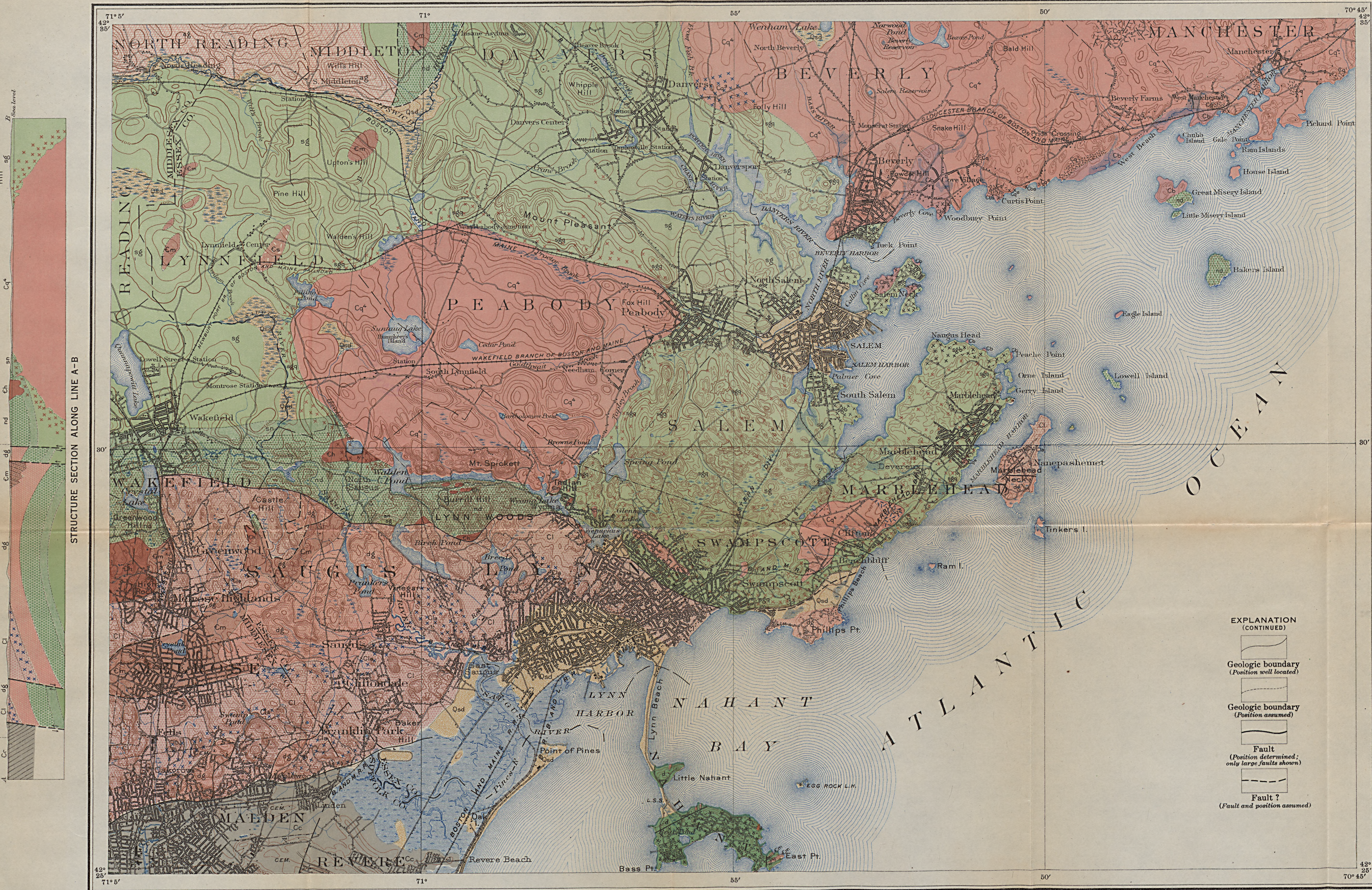
LATE CARBONIFEROUS OR POST-CARBONIFEROUS
- ag — Andover granite (*As mapped it includes some areas of older gneiss*)
- g — Gabbro associated with Dracut diorite

CARBONIFEROUS
- sgr — Squam granite
- Cl — Lynn volcanics (*In southern or typical area probably Carboniferous; in northern area (mapped as Newbury volcanic complex by B. K. Emerson) probably Devonian*)
- Cq — Quincy granite
- Cqs — Quartz syenite or nordmarkite
- Cb — Beverly syenite (pulaskites and umptekites) and nephelite syenite

DEVONIAN (?)
- dg — Dedham granodiorite
- nd — Newburyport quartz diorite
- sg — Salem gabbro-diorite
- sgs — Salem gabbro-diorite with amphibolite schist
- gd — Gabbro and diabase

Fault (*Location assumed in places*)

Geologic boundary (*Location assumed in places*)



Base from U. S. Geological Survey Lawrence, Salem, Boston, and Boston Bay topographic maps

GEOLOGIC MAP AND STRUCTURE SECTION OF PARTS OF ESSEX, SUFFOLK, AND MIDDLESEX COUNTIES, MASSACHUSETTS

Geology by C. H. Clapp 1907–1910

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.
Datum is mean sea level.

1920

EXPLANATION

SEDIMENTARY AND METAMORPHIC ROCKS

QUATERNARY
- Qsd — Surficial deposits of Recent and Pleistocene age

CARBONIFEROUS
- Cc — Cambridge slate

CAMBRIAN AND ALGONKIAN (?)
- Cs — Serpentine
- Ch — "Hornfels"
- Cm — Metamorphic sediments (Quartzite, slates, schists, and marbles)

IGNEOUS ROCKS

LATE CARB. OR POST-CARB.
- ag — Andover granite

CARBONIFEROUS
- Cl, Cla — Lynn volcanics (Quartz keratophyre, trachyte, dacite, and andesite flow rocks; agglomerates and breccias = Cla)
- Quincy granite:
  - Fine-grained granite
  - Cqᵖ — Porphyritic granite
  - Cqᵉ — Granite variation in East Danvers
  - Cqⁿ — Normal granite
  - Quartz syenite or nordmarkite
  - Cqˣ — Granite with numerous xenoliths chiefly of Salem gabbro-diorite
- Cb — Beverly syenite (pulaskites and umptekites) and nephelite syenite
- Cbx — Beverly syenite with numerous xenoliths chiefly of Salem gabbro-diorite

DEVONIAN (?)
- dg — Dedham granodiorite
- nd — Newburyport quartz diorite
- sn — Probably transition between Salem gabbro-diorite and Newburyport quartz diorite
- sg — Salem gabbro-diorite (Gabbro-diorite, gabbro, diorite, and gneiss)
- sgq — Salem gabbro-diorite, brecciated and cut by Quincy granite*
- sgb — Salem gabbro-diorite, brecciated and cut by Beverly syenite
- d — Diabase
- Gabbro with quartz syenite differentiate (a)

Note.—Density of crosses in Beverly syenite and Salem gabbro-diorite indicates relative amount of igneous intrusives

* The Quincy granite also cuts the adjoining Newburyport quartz diorite and the hornfels where shown by brown crosses.

POLITECHNIKA GDAŃSKA
ZAKŁAD GEOLOGII

Analyses of rocks in Essex County.

No.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	H_2O+.	H_2O−.	CO_2.	TiO_2.	P_2O_5.	MnO.	BaO.	Sum.	Sp. gr.	Inclusive.	Norm.	Locality.	Analyst.	Reference.	Rock name as cited by author.	Remarks.
Class I. Persalane. Order 4. Quardofelic. Brittannare. Rang 1. Peralkalic. Liparase. Subrang 3. Sodipotassic. Liparose.																								
16 A3.III	77.61 1.294	11.94 .117	0.55 .004	0.87 .012	Trace.	0.31 .006	3.80 .061	4.98 .053	0.23	Trace.		0.25 .003		Trace.		100.54	2.618		q 35.76 di 0.65 or 29.47 hy 0.26 ab 31.96 mt 0.93 an 0.83 il 0.46	Rockport, Cape Ann.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 6, p. 793, 1898.	Hornblende granite.	
17 A3.III	77.49 1.292	11.89 .117	0.34 .002	1.12 .015	0.09 .002	0.45 .008	4.58 .074	4.26 .045	0.16					Trace.		100.63			q 33.42 ac 0.92 or 25.02 di 1.95 ab 37.73 hy 1.16	Bass Rocks, Cape Ann.	Do.	Idem, vol. 7, p. 107, 1899.	Aplite.	Border of dike.
18 A3.III	76.44 1.274	12.95 .127	0.19 .001	0.89 .012	Trace.	0.15 .003	4.76 .077	4.95 .053	0.09			0.37 .005		Trace.		100.79			q 29.16 ac 0.46 or 29.47 di 0.75 ab 39.82 hy 0.53 il 0.76	Bass Rocks, Cape Ann.	Do.	Idem, p. 107.	Aplite.	Center of dike.
19 A3.III	76.49 1.275	11.89 .117	1.16 .007	1.56 .022	Trace.	0.14 .002	4.03 .064	5.00 .053	0.38	0.12		Trace.		Trace.		100.77	2.650		q 33.12 di 0.49 or 29.46 hy 1.72 ab 33.54 mt 1.62	Magnolia.	Do.	Idem, p. 113.	Paisanite.	
20 A3.III	71.40 1.190	14.76 .145	1.68 .011	0.72 .010	0.55 .014	0.10 .002	4.79 .077	5.16 .055	1.46					Trace.		100.62			q 22.80 hy 1.40 or 30.58 mt 2.32 ab 40.35 hm 0.16 an 0.56 c 1.12	Marblehead Neck.	H. S. Washington.	Idem, p. 293.	Keratophyre (bostonite).	
21 A2.II	70.23 1.171	15.00 .147	1.99 .012	N. d. (.024)	0.38 .010	0.33 .006	4.98 .080	4.99 .053	1.28	0.91		0.03	0.06	0.24	 .003	100.42			q 19.62 hy 4.17 or 29.47 il 0.46 ab 41.92 an 1.67 c 0.82	Do.	T. M. Chatard.	Sears, J. H., Harvard Coll. Mus. Comp. Zool. Bull., vol. 16, p. 170, 1890.	Do.	
22 A2.II	67.35 1.123	15.05 .148	1.23 .008	4.76 .066	0.03 .001	0.55 .010	4.42 .071	6.08 .065	0.17	0.16		0.60 .008		0.05 .001		100.45	2.691		q 14.06 hy 6.70 or 36.14 mt 1.86 ab 37.20 il 1.22 an 2.78 c 0.20	Pigeon Hill quarry, Rockport, Cape Ann.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 6, p. 795, 1898.	Quartz syenite.	Inclusion in granite No. 16, above.
23 A1.I	71.90 1.198	12.98 .127	0.81 .005	2.85 .040	0.02	1.04 .019	4.19 .068	5.60 .060	0.20	0.20		0.34 .004	0.04	0.08 .001	Trace.	99.87	2.651	ZrO_2 0.12 SrO trace.	q 22.80 ac 0.46 or 33.36 di 4.71 ab 35.11 hy 1.85 mt 0.93 il 0.61	Quarry, South Lynnfield.	M. F. Connor.	This paper.	Quincy granite.	
Subrang 4. Dosodic. Kallerudose.																								
8 A3.III	69.64 1.161	13.04 .128	4.15 .026	1.98 .028	0.32 .008	0.54 .010	5.46 .088	3.55 .038	0.69			0.55 .007				99.92	2.673		q 23.10 di 1.73 or 21.13 mt 4.87 ab 46.11 il 1.06 an 0.56 hm 0.76	West Lynn.	S. J. Schofield.	This paper.	Quartz keratophyre.	Lynn volcanics.
Rang 2. Domalkalic. Toscanase. Subrang 3. Sodipotassic. Toscanose.																								
14 A3.III	68.88 1.148	14.96 .146	0.64 .004	4.64 .064	0.37 .009	1.74 .031	3.83 .062	4.97 .053	0.24	0.06		Trace.		Trace.		100.33	2.696		q 19.62 hy 8.82 or 29.47 mt 0.83 ab 32.49 an 8.62	Squam Light.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 109, 1899.	Quartz syenite porphyry.	
15 B3.IV	68.36 1.139	16.58 .163	0.90 .006	3.24 .045	0.45 .011	1.85 .033	3.97 .064	5.27 .056	0.17	0.18		Trace.		Trace.		100.97			q 18.18 hy 6.25 or 31.13 mt 1.39 ab 33.54 an 9.17 c 1.02	Wolf Hill, North Gloucester.	Do.	Idem, vol. 6, p. 800, 1898.	Nordmarkite.	
16 A2.II	66.60 1.110	15.05 .148	1.07 .007	4.42 .061	0.36 .009	2.21 .039	4.03 .065	5.42 .058	0.41					Trace.		100.33	2.612		q 15.24 di 3.41 or 32.25 hy 5.06 ab 34.06 mt 1.62 an 6.95 il 1.37	Prospect Street, Gloucester.	Do.	Idem, p. 798.	Akerite.	
Subrang 4. Dosodic. Lassenose.																								
9 A3.III	70.64 1.177	15.34 .150	1.83 .011	1.10 .014	0.52 .013	1.24 .022	5.23 .084	3.55 .038	0.38	0.14		0.90 .011		Trace.		100.87	2.632		q 23.28 hy 1.30 or 21.13 mt 0.70 ab 44.02 il 0.67 an 6.12 hm 1.28 c 0.61	Marblehead Neck.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 292, 1899.	Rhyolite.	
Rang 3. Alkalicalcic. Coloradase. Subrang 4. Dosodic. Yellowstonose.																								
4 B2.III	68.94 1.149	14.11 .138	1.68 .008	2.88 .040	0.80 .020	4.62 .082	3.53 .056	2.41 .026	1.13	0.22		0.50 .006	0.08	0.05	0.04	100.99	2.723		q 28.56 di 6.07 or 14.46 hy 1.99 ab 29.34 mt 2.55 an 15.57 il 0.91	Saugus.	M. F. Connor.	This paper.	Dedham granodiorite.	
Order 5. Perfelic. Canadare. Rang 1. Peralkalic. Nordmarkase. Subrang 3. Sodipotassic. Phlegrose.																								
5 A3.III	63.71 1.062	18.30 .180	2.08 .013	2.52 .035	0.09 .002	1.18 .021	6.39 .103	6.21 .065	0.17	0.09		Trace.		Trace.		100.74			q 0.42 di 2.20 or 36.14 hy 1.95 ab 53.97 mt 2.32 an 3.34	Salem Neck.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 6, p. 806, 1898.	Hedrumitic pulaskite.	
6 A3.III	61.05 1.018	18.81 .183	2.02 .013	3.06 .043	0.42 .011	1.30 .023	6.56 .106	6.02 .064	0.78			0.34 .004		Trace.	None.	100.04	2.655		or 35.58 di 2.38 ab 47.68 ol 2.50 an 3.61 mt 3.02 ne 4.26 il 0.61	Coney Island, Salem Harbor.	Do.	Idem, vol. 7, p. 118, 1899.	Sölvsbergite.	Near nordmarkose.
Subrang 4. Dosodic. Nordmarkose.																								
6 A2.III	63.09 1.052	18.44 .180	2.90 .018	1.36 .019	0.16 .004	1.00 .018	7.25 .117	5.23 .056	0.62	0.21		0.45 .006		Trace.		100.77		ZrO_2 0.06	or 31.14 di 1.86 ab 59.21 wo 0.81 an 1.95 mt 3.02 ne 1.14 il 0.91 hm 0.80	Salem Neck.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 6, p. 806, 1898.	Pulaskite.	
7 A2.II	60.60 1.010	18.28 .180	2.85 .018	2.67 .037	0.52 .013	0.99 .018	6.66 .107	5.73 .061	0.69			0.71 .009	0.15 .001			99.85			or 33.92 di 0.68 ab 51.09 ol 1.69 an 3.34 mt 4.18 ne 2.70 il 1.37 ap 0.34	Coney Island, Salem Harbor.	M. Dittrich.	Rosenbusch, H., Elemente der Gesteinslehre, p. 199, 1898.	Syenite porphyry, sölvsbergite.	
8 B3.IV	59.31 .989	22.50 .221	1.93 .012	1.40 .019	0.17 .004	0.46 .008	7.98 .129	4.08 .043	1.12	0.15		0.32 .008		Trace.		99.42	2.599		or 23.91 ol 0.59 ab 59.21 mt 2.78 an 2.22 il 0.61 c 4.18	Great Haste Island, Salem Harbor.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 6, p. 803, 1898.	Foyaite.	
Order 6. Lendofelic. Russare. Rang 1. Peralkalic. Miaskase. Subrang 4. Dosodic. Miaskose.																								
4 A2.II	58.77 .980	22.53 .220	1.54 .010	1.04 .014	0.19 .005	0.74 .013	9.62 .155	4.89 .052	0.90	0.07		0.31 .004		Trace.	None.	100.71	2.596	ZrO_2 0.11	or 28.91 ol 0.35 ab 42.97 mt 2.32 an 3.61 il 0.61 ne 20.73	Salem Neck.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 6, p. 803, 1898.	Foyaite.	
5 A2.II	56.75 .946	20.69 .203	3.52 .022	0.59 .008	0.11 .003	0.37 .007	11.45 .185	2.90 .031	3.18	0.04		0.30 .004		Trace.	None.	100.12	2.474	SO_3 trace Cl 0.28	or 17.24 ac 6.01 ab 46.64 di 0.65 ne 23.57 wo 0.46 mt 0.93 il 0.61 hm 0.80	Pickard Point, Manchester.	Do.	Washington, H. S., Am. Jour. Sci., 4th ser., vol. 6, p. 185, 1898.	Analcite tinguaite.	
Class II. Dosalane. Order 5. Perfelic. Germanare. Rang 1. Peralkalic. Umptekase. Subrang 3. Sodipotassic. Ilmenose.																								
4 A2.II	62.99 1.050	14.25 .140	2.78 .017	5.15 .072	1.30 .033	2.72 .049	4.86 .078	6.35 .068	0.18			0.16 .002		0.18 .003		100.92	2.732		q 2.52 ac 2.77 or 37.81 di 11.60 ab 37.73 hy 5.56 mt 2.55	Beverly.	F. E. Wright.	Wright, F. E., Min. pet. Mitt., vol. 19, p. 318, 1900.	Umptekite.	
Subrang 4. Dosodic. Umptekose.																								
5 A2.II	64.28 1.071	15.97 .156	2.91 .018	3.18 .044	0.03 .001	0.85 .015	7.28 .117	5.07 .054	0.20			0.50 .006	0.08	Trace.	None.	100.33	2.703		q 2.04 ac 6.93 or 30.03 di 3.72 ab 53.45 hy 2.74 mt 0.70 il 0.91	Andrews Point, Cape Ann.	H. S. Washington.	Washington, H. S., Am. Jour. Sci., 4th ser., p. 178, 1898.	Glaucophane sölvsbergite.	
Rang 3. Alkalicalcic. Andase. Subrang 4. Dosodic. Andose.																								
8 A3.III	51.82 .864	17.06 .167	1.97 .012	8.60 .120	4.87 .122	8.59 .153	3.44 .056	1.77 .019	0.20	0.11		2.15 .027				100.58			or 10.56 di 13.98 ab 29.34 hy 8.36 an 25.58 ol 5.59 mt 2.78 il 4.10	Peache Point, Marblehead.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 60, 1899.	Diorite.	
9 A2.II	49.84 .831	17.45 .171	1.64 .010	9.43 .131	4.77 .119	8.34 .149	3.90 .063	1.35 .015	0.54	0.26	None.	1.56 .020	0.10 .001	0.15 .002	Trace.	99.45	3.090	S 0.12 .003	or 8.34 di 12.25 ab 31.44 ol 14.69 an 25.85 mt 2.32 ne 0.85 il 3.04 ap 0.34	Railroad cut, east of Montrose station, Lynnfield.	M. F. Connor.	This paper.	Gabbro-diorite.	
Rang 4. Docalcic. Hessase. Subrang 4–5. Presodic. Hessose.																								
8 B2.III	43.73 .729	20.17 .198	4.32 .027	6.93 .097	3.91 .098	10.99 .196	2.42 .039	1.45 .015	1.02	0.08		4.23 .053	0.15 .001	Trace.		99.40	3.058		or 8.34 di 10.80 ab 18.60 ol 4.94 an 40.03 mt 6.26 il 8.06 ap 0.34	Nahant.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 63, 1899.	Gabbro.	Sum low.
Order 6. Lendofelic. Norgare. Rang 2. Domalkalic. Essexase. Subrang 4. Dosodic. Essexose.																								
4 A2.II	47.94 .799	17.44 .171	6.84 .043	6.51 .090	2.07 .052	7.47 .133	5.63 .091	2.79 .030	2.04			0.20 .003	1.04 .007			99.92			or 16.68 di 13.82 ab 26.20 ol 3.06 an 13.94 mt 9.98 ne 11.64 il 0.46 ap 2.35	Salem Neck.	M. Dittrich.	Rosenbusch, H., Elemente der Gesteinslehre, p. 172, 1898.	Essexite.	TiO_2 low?.
5 A2.II	46.99 .783	17.94 .176	2.56 .016	7.56 .105	3.22 .081	7.85 .140	6.35 .102	2.62 .028	0.65			2.92 .035	0.94 .007	Trace.	None.	99.60	2.919		or 15.57 di 16.24 ab 18.86 ol 5.31 an 12.79 mt 3.71 ne 18.74 il 5.32 ap 2.35	Do.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 57, 1899.	Do.	
Rang 3. Alkalicalcic. Salemase. Subrang 4. Dosodic. Salemose.																								
5 A3.III	45.32 .756	18.99 .186	3.78 .023	9.78 .136	4.68 .117	9.19 .164	3.78 .161	2.12 .023	0.31	0.09		1.94 .024				99.98	2.975		or 12.79 di 14.25 ab 12.84 ol 12.06 an 28.36 mt 5.34 ne 11.64 il 3.65	Salem Neck.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 63, 1899.	Hornblende gabbro.	
Class III. Salfemane. Order 5. Perfelic. Gallare. Rang 3. Alkalicalcic. Camptonase. Subrang 4. Dosodic. Camptonose.																								
6 A2.II	47.12 .785	14.43 .142	3.33 .021	11.71 .163	6.05 .151	9.63 .172	2.58 .042	1.11 .012	0.34	0.28		3.27 .041				99.85			or 6.67 di 19.23 ab 22.01 hy 7.46 an 24.46 ol 8.42 mt 4.87 il 6.23	Rockport, Cape Ann.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 289, 1899.	Diabase.	Ophitic in large quarry.
Rang 4. Docalcic. Auvergnase. Subrang 4–5. Presodic. Auvergnose.																								
12 A3.III	46.59 .777	17.55 .172	1.68 .011	10.46 .145	7.76 .194	10.64 .190	3.31 .053	0.72 .008	0.07	0.10		1.41 .018				100.29	3.047		or 4.45 di 18.02 ab 16.77 ol 18.92 an 30.86 mt 2.55 ne 5.96 il 2.74	Salem Neck.	H. S. Washington.	Washington, H. S., Jour. Geology, vol. 7, p. 285, 1899.	Camptonite.	

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